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# THE IMPACT OF RENTON WASTEWATER TREATMENT PLANT ON WATER QUALITY OF THE LOWER GREEN / DUWAMISH RIVER

January 1981

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DOE 81-2

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# LOWER GREEN/DUWAMISH RIVER

## Part I

## EFFECTS OF RENTON WASTEWATER TREATMENT PLANT EFFLUENT ON WATER QUALITY OF THE LOWER GREEN/DUWAMISH RIVER

by

John C. Bernhardt

## Part II

## THE IMPACT OF EFFLUENT FROM THE RENTON WASTEWATER TREATMENT PLANT ON THE DISSOLVED OXYGEN REGIMEN OF THE LOWER GREEN/DUWAMISH RIVER

by

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January 1981

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DOE Report No. 81-2

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Part I

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ABSTRACT

Two time-of-travel surveys were conducted on the lower Green-Duwamish River to evaluate impacts of secondary-treated wastewaters discharged from Renton treatment plant during summer low flow. Drogues were placed in the river near the outfall on September 18 and October 2, 1979 and followed by boat until reaching the mouth at Elliott Bay. Samples were collected for the determination of: temperature; pH; conductivity; dissolved oxygen; fecal coliforms; BOD; COD; nutrients; and other indicators of stream quality. Flow and other physical data important for assessing stream quality also were obtained.

The drogues nearly reached the river mouth in 24 hours during both surveys, reversing direction twice during this period and moving upriver in response to the influx of estuarine waters at high tide. Stream quality was generally poor and this condition was associated mainly with Renton WTP. At 4:1 and 4.4:1, the stream-to-effluent dilution ratios were far below the 20:1 recommended minimum. Violations of state standards for temperature and dissolved oxygen were observed. EPA red book criteria for total residual chlorine and ammonia (un-ionized) were exceeded while nitrite-nitrogen reached borderline levels. These problems are accentuated when waters near the outfall reverse direction at high tide forming poorly diluted blocks of effluent/river water.

The ability of the Green-Duwamish River to assimilate wastewaters discharged by RWTP appears to be exceeded at the current 36 MGD rate of discharge. Problems associated with the plant will continue to become more acute as the plant approaches the 144 MGD ultimate site capacity.

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# EFFECTS OF RENTON WASTEWATER TREATMENT PLANT EFFLUENT ON WATER QUALITY OF THE LOWER GREEN/DUWAMISH RIVER

## Introduction

The Municipality of Metropolitan Seattle (METRO) completed Renton Wastewater Treatment Plant (RWTP) in 1965 as part of a comprehensive water pollution abatement program initiated to improve water quality in Lake Washington and nearby areas. Municipal, industrial, and domestic wastes generated along much of the east shore of the lake, parts of south and west Seattle, as well as Renton, Auburn, and some other southern King County communities were diverted to the new secondary treatment facility. Dechlorinated wastewaters generated by RWTP are discharged to the Green-Duwamish River for disposal and dispersion. This facility is the major point-source discharger on the stream.

The RWTP discharge has increased at a fairly constant rate during the 15-year life of the facility to the point where it now represents a substantial portion of Green-Duwamish flow during some times of the year. During dry weather, the discharge averages about 56 cubic feet per second (cfs), or some 36 million gallons per day (MGD). It is increasing at an annual rate of about 1.7 MGD with a 144 MGD ultimate site capacity (Finger, personal communication). The most critical time of year is late summer and fall when warm water temperatures prevail and river flows may decline to 150 cfs or less.

As RWTP has grown, the Department of Ecology (DOE) likewise has become increasingly concerned about impacts the discharge may be having on stream quality. Of particular concern is the "freshwater" portion of river extending from the outfall downstream to the estuarine waters of the dredged waterway at the mouth. Past investigators have concentrated mainly on the lower waterway and zone of salt water intrusion which at times extends for some distance up-river, while the fresh waters above have received limited attention. The need for such information is especially evident at this time because METRO, DOE, and EPA are negotiating a plan for upgrading the plant which will have far-reaching implications in terms of Green-Duwamish water quality. A solid base of data on existing conditions is needed so that the most informed management decisions can be made concerning this facility upgrade and future status of the river.

In response to the need for additional information, DOE conducted an extensive water quality survey on the freshwaters of the lower Green-Duwamish during late 1979. The purpose was to assess stream conditions during summer low-flow with emphasis on measuring impacts of Renton treatment plant. The results are presented in two reports. This report (No. 1) describes the dilution and dispersion of RWTP wastewaters plus selected water quality constituents measured above and for some distance below the outfall provide measure of stream impacts. A detailed modeling analysis of the dissolved oxygen regime below the RWTP outfall is given in the second report (No. 2).

## Background

The name "Green-Duwamish" is applied to the study area because the Green River is the only large stream that flows into the Duwamish. Originally, the Duwamish (Indian word for "many colors") was fed by three rivers; White, Black, and Green. In 1906, the White River was diverted permanently to the Puyallup. Then, in 1916, the Black River was reduced to a trickle when Lake Washington, the principal source, dropped some 3 meters after the Lake Washington Ship Canal was completed (Dawson and Tilley, 1972). These and other changes have reduced the Duwamish drainage to about 1/4 of its original size (DOE, 1980).

Two indices of river distance are used by investigators involved in studies of the Green-Duwamish and this should be considered when interpreting or attempting to compare the various reports. Also, both kilometers and miles (statute) have been used as measures of distance. The metric system will be used in this report with statute mileage equivalents given in parentheses where deemed appropriate. The standard river mile index (converted to metric equivalents) developed for streams throughout Washington State by the Pacific Northwest River Basins Commission (1969) is employed. This index places river km 0.0 at the elbow of the Duwamish west waterway (Figure 1). The alternate index system used by some investigators (Welsh, E.B. and W.T. Trial, 1979; Dawson, W.A. and L.J. Tilley, 1972; etc.) places river km 0.0 at the northern tip of the west bank of the west waterway, resulting in a 1.4 km (0.9 mile) difference between the two systems. Well-known landmarks also are referenced where deemed appropriate.

Flow and velocity measurements are given in the English System.

## Location and Description

Renton wastewater treatment plant is located in the lower Green River valley about four kilometers southwest of Renton. Secondary-treated wastewaters are piped some 200 meters to the Green-Duwamish and discharged via an eight-chambered diffuser (River Km 19.3) partially embedded in the river bed. The diffuser extends about 10 meters across a 30-meter wide section of the stream which averages about one meter deep during low-slack tide.

The Green-Duwamish changes slowly from a typical forested upland stream to a fairly open watercourse as it flows through the rapidly developing lowlands of the middle Green River valley, then transcends to generally slough-like in appearance as it meanders through the lower valley. Below RWTP the river meets the latter description being characterized by steep banks composed of sand, mud, and a small amount of clay. The stream bottom along this river section is composed of similar material. Thickets and dense underbrush cover much of the river bank.

Tidal influence first becomes an important water quality consideration near the RWTP. Several kilometers below, the river meets and begins to intermix with the estuarine waters of Elliott Bay. Saline waters are known to intrude in the form of a wedge as far upstream as a little above the East Marginal Way Bridge at River Km 13.0 (about 8 miles), during periods of low flow. Salt water intrusion averages about 8 km during high flows.

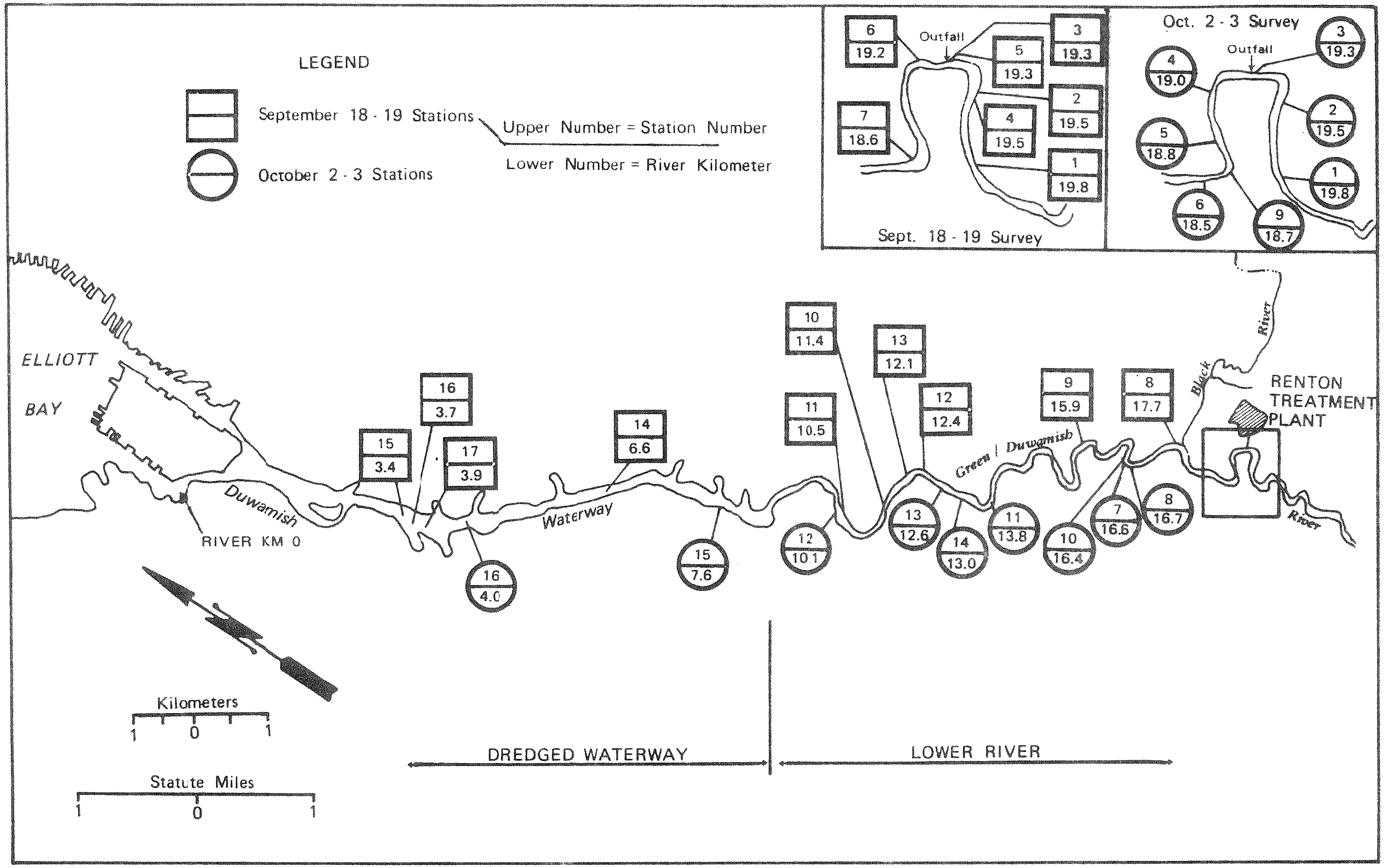


Figure 1. MAP SHOWING LOCATIONS OF GREEN – DUWAMISH STATIONS SAMPLED DURING DOE SEPTEMBER AND OCTOBER 1979 TIME - OF - TRAVEL STUDY.

During summer low flow, the river below the RWTP averages about 2 meters deep and 15 to 20 meters wide. Flow velocities are typically slow with few, if any, riffles evident even during low tide.

Flows in the Green-Duwamish for the most part are controlled by Howard A. Hanson Dam at river km 103 (R.M. 64) above Palmer. The dam was completed in 1962 for the purposes of flood control and low-flow augmentation in the lower river. The City of Tacoma diverts an average of 112 cfs below the dam. The dam limits the maximum discharge below the diversion to 12,000 cfs during winter and a minimum of 110 cfs during summer. The 110 summer minimum is not considered adequate by the Washington State Departments of Fisheries and Game to meet fishery resource needs (DOE, 1980). A minimum discharge of 300 cfs has been established through the Instream Resources Protection Program (WAC 173-509), but even with this requirement, extreme summer low flows are expected to continue due to existing water rights.

Three species of Pacific salmon utilize the Green-Duwamish for migration, reproduction, and rearing - chinook, coho, and chum. Anadromous game fish using these waters include steelhead, sea-run cutthroat trout, and dolly varden (Williams, et al., 1975). The timing of the freshwater life phases of salmon in the Green-Duwamish is shown in Table 1.

Sport fishing for salmon and trout is a major recreation activity on the Green-Duwamish. Washington State Department of Game seasonal catch statistics ranks the river about seventh in the state for steelhead (WDG, 1978 and 1979). Anglers fish along the lower river wherever access is possible. Other activities include boating and aesthetics.

The shallow depth, partially submerged and sunken logs, and other debris make navigation by boat extremely difficult during low tide stage.

## Methods

Impacts that unstable constituents such as dissolved oxygen, biochemical oxygen demand, and ammonia may have on a stream and the ability of the stream to assimilate waste loads which exert such demands are most accurately measured by the time-of-travel method for assessing self-purification processes. The advantage of this approach is that, ideally, the same "block" of stream water can be sampled periodically over time as wastewaters move down-river.

For the Green-Duwamish effort, the 19.3 km (12 river mile) section of the lower river between RWTP and Harbor Island at the mouth was drift-floated on two occasions, September 18-19 and October 2-3, 1979. Seasonal low-flow conditions prevailed in each case. The first drift was initiated at near high slack tide, whereas the second drift started near low slack water. Two small surface drogues were placed in the stream near the RWTP outfall at the onset of each drift, then followed by boat for the duration of the survey. Periodically the drogues were retrieved from quiet areas or obstacles such as tree limbs and snags, and positioned equal-distance across the stream channel. Since main-channel waters move at a velocity greater than the entire stream, a correction factor of 0.85 was applied to all time measurements obtained (Kittrell, 1969).

TABLE 1. Timing of salmon and searun trout fresh water life phases in Green-Duwamish River Basin[4]

| Species | Fresh-water Life Phase | J | F | M | A | M | J | J | A | S | O | N | D |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Summer-Fall chinook | Upstream migration | | | | | | ■ | ■ | ■ | ■ | ■ | ■ | |
| | Spawning | | | | | | | | | ■ | ■ | ■ | |
| | Intragravel develop. | ■ | ■ | | | | | | | ■ | ■ | ■ | ■ |
| | Juvenile rearing | ■ | ■ | ■ | ■ | ■ | ■ | ■ | | | | | |
| | Juv. out migration | | | | ■ | ■ | ■ | ■ | | | | | |
| Coho | Upstream migration | ■ | | | | | | | ■ | ■ | ■ | ■ | ■ |
| | Spawning | ■ | | | | | | | | | | ■ | ■ |
| | Intragravel develop. | ■ | ■ | ■ | ■ | | | | | | | ■ | ■ |
| | Juvenile rearing | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
| | Juv. out migration | | | | ■ | ■ | ■ | ■ | | | | | |
| Chum | Upstream migration | ■ | | | | | | | | ■ | ■ | ■ | ■ |
| | Spawning | ■ | | | | | | | | | | ■ | ■ |
| | Intragravel develop. | ■ | ■ | ■ | ■ | | | | | | | ■ | ■ |
| | Juvenile rearing | | ■ | ■ | ■ | ■ | ■ | ■ | | | | | |
| | Juv. out migration | | ■ | ■ | ■ | ■ | ■ | ■ | | | | | |
| Summer steelhead | Upstream migration | | | | ■ | ■ | ■ | ■ | ■ | ■ | ■ | | |
| | Spawning | | ■ | ■ | ■ | ■ | ■ | | | | | | |
| | Intragravel develop. | | ■ | ■ | ■ | ■ | ■ | ■ | | | | | |
| | Juvenile rearing* | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
| | Juv. out migration | | | ■ | ■ | ■ | ■ | ■ | | | | | |
| Winter steelhead | Upstream migration | ■ | ■ | ■ | ■ | ■ | ■ | | | | | ■ | ■ |
| | Spawning | ■ | ■ | ■ | ■ | ■ | ■ | | | | | | ■ |
| | Intragravel develop. | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | | | | ■ |
| | Juvenile rearing* | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
| | Juv. out migration | | | ■ | ■ | ■ | ■ | ■ | | | | | |
| Searun cutthroat | Upstream migration | ■ | | | | | | ■ | ■ | ■ | ■ | ■ | ■ |
| | Spawning | ■ | ■ | ■ | | | | | | | | | |
| | Intragravel develop. | ■ | ■ | ■ | ■ | ■ | ■ | | | | | | |
| | Juvenile rearing* | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
| | Juv. out migration | | | ■ | ■ | ■ | ■ | | | | | | |

*Normally extends over a two-year period.

Samples initially were collected at 15-minute intervals, then the sampling interval was increased to 30, 60, 90, 120, and 180 minutes as the drift progressed. Sampling at the 180-minute interval continued for the duration once it was reached. The following water quality analyses were performed:

| Laboratory | Field |
|---|---|
| Turbidity (NTU) | Temperature (°C) |
| Dissolved Oxygen (mg/l) (Winkler) | Specific Conductance (μmhos/cm) |
| Fecal Coliform (col/100 ml) | pH (S.U.) |
| BOD (mg/l) | Total Residual Chlorine (mg/l) |
| COD (mg/l) | |
| Nitrate-N (mg/l) | |
| Nitrite-N (mg/l) | |
| Ammonia-N (mg/l) | |
| Total Kjeldahl-N (mg/l) | |
| Orthophosphate-P (mg/l) | |
| Total phosphate-P (mg/l) | |
| Total suspended solids (mg/l) | |
| Total Alkalinity ($CaCO_3$) (mg/l) | |
| Chlorophyll a (μg/l) | |
| Pheophytin a (μg/l) | |

For the field parameters, specific conductance was measured with a Beckman Solu-bridge, Type RB-5 probe. An Orion Research Ionalyzer/Model 399 A probe was used to determine pH. Total residual chlorine was determined by the DPD ferrous titrimetric method described in *Standard Methods for the Examination of Water and Wastewater* (APHA, AWWA, and WPCF, 1976). Samples for laboratory analysis were packed in ice (if required) and transported to the Department of Ecology laboratory in Tumwater. All analyses were performed according to *Standard Methods* (ibid) or *Methods for Chemical Analyses of Water and Wastes* (EPA, 1979). Un-ionized ammonia was calculated from the ammonia-nitrogen data based on pH and temperature conversion (Thurston, et al., 1974).

All parameters were not measured at every sampling station during both drifts in an effort to keep within laboratory load limits.

At low tide before each drift, stream flow was measured immediately above the RWTP outfall with a Marsh-McBernie Model 201 portable current meter. Measurements were made at two-foot intervals across the stream channel. RWTP discharge data also were obtained at this time. Stream physical characteristics and other possible factors along the study area, which might be important to interpretation of the data, were visually assessed.

Additional drogue surveys were conducted on November 8 and 15, 1979 near the RWTP to strengthen the data base concerning the formation of poorly-diluted blocks of river-plus-effluent wastewater. Changes in water quality were monitored during flow reversal at high tide. These two surveys were limited to the first three kilometers (2 miles) below the outfall and a short distance above.

## Results and Discussion

### Wastewater Dispersion and Dilution

For both surveys the surface drogues took about 24 hours to traverse the 15.5-kilometer (9.7-mile) section of the Green-Duwamish between RWTP and the First Avenue Bridge above Harbor Island. Flow reversal occurred twice during each drift. The estuarine waters appear to slowly move through the wide navigation channel near the river mouth, accelerate considerably after the river constricts, then slow as the river's water overcome tidal influence. This is demonstrated when the distances traveled upriver during flow reversal are compared by stream location (Figure 2).

Although not measured, the stream waters probably occillate for a period in the lower 3-Km (2-mile) section of river before reaching Elliott Bay.

Comparison of the Green-Duwamish flow measurements taken immediately above the RWTP outfall with concurrent RWTP discharge measurements demonstrate extremely low stream/effluent dilution ratios at the time of both drifts:

| Date | River Discharge | RWTP Discharge | River discharge below RWTP | Dilution Ratio |
|---|---|---|---|---|
| 09/19/79 | 274 (177)[1/] | 68 (44) | 342 (221) | 4:1 |
| 10/02/79 | 210 (136) | 48 (31) | 258 (167) | 4.4:1 |

As a general guideline, pollution problems may be expected to develop in a stream when the dilution of secondary municipal wastewaters drops below a ratio of about 20:1. This criterion is addressed in chapter 25 of the *Effluent Dilution Zone Guidelines* (March 1980 revision) published by the State of Washington (DOE, 1978). The state guidelines require that dilution calculations be based on the 7-day, 10-year low flow or other low-flow conditions established by regulation. A 7-day/10-year low flow of 107 cfs has been established for the Green-Duwamish at River Km 51.3 near Auburn (USGS, 1973). A corresponding low flow value has not been developed for the river near RWTP (River Km 19.3); however the flow at this location can be estimated from the following drainage area relationship:

$$\text{Low flow near RWTP} = \frac{(107 \text{ cfs at Auburn})(440 \text{ sq. mi. above RWTP})}{(399 \text{ sq. mi. above Auburn})}$$
$$= 118 \text{ cfs}$$

The relationship between the monthly low flows at the USGS Tukwila gaging station (near the RWTP) and the USGS Auburn station also can be used to estimate the 7-day/10-year low flow near the facility:

[1/] cfs (MGD)

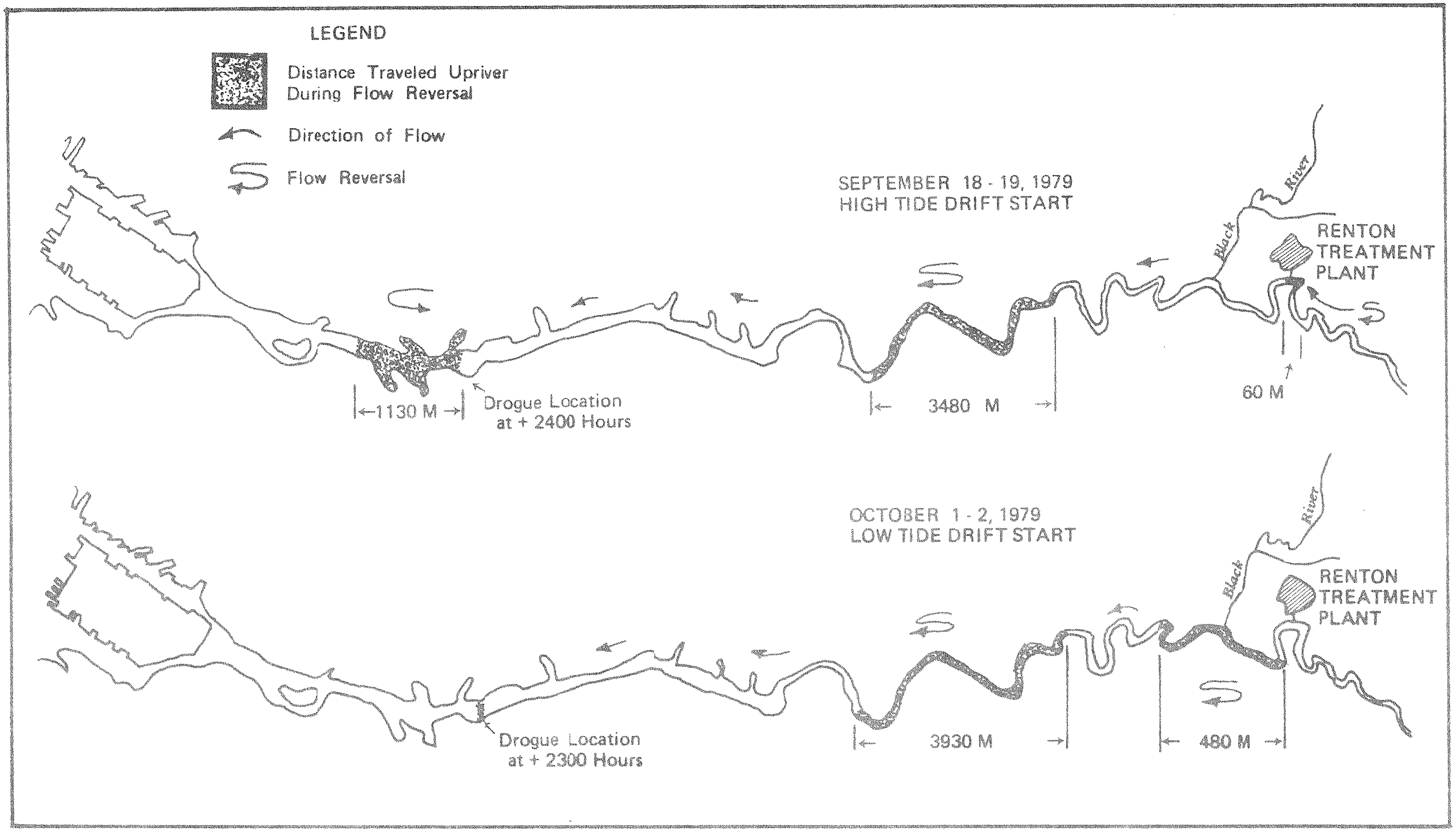


Figure 2. MAP OF GREEN – DUWAMISH RIVER SHOWING SURFACE DROGE MOVEMENT DURING DOE SEPTEMBER AND OCTOBER, 1979 TIME - OF - TRAVEL SURVEY

| Low-Flow Month | Tukwila flow (cfs) | Auburn flow (cfs) | Percent Difference |
|---|---|---|---|
| Sept. 79 | 294 | 257 | 13 |
| Aug. 78 | 353 | 306 | 13 |
| Aug. 77 | 299 | 257 | 14 |

Assuming a 13.3 percent average difference, an estimated 7-day/10-year low flow of 121 cfs would result. A 120-cfs low flow for the Green-Duwamish near RWTP would seem appropriate for use in this report.

Using a 120-cfs low flow and an average annual growth rate of 1.7 MGD for the RWTP during dry weather, the following "worst-case" dilution ratios would be expected:

| Year | Renton Discharge cfs (MGD) | Dilution Ratio Stream:RWTP |
|---|---|---|
| 1979 | 53 ( 34) | 2.3:1 |
| 1985 | 68 ( 44) | 1.8:1 |
| 1990 | 82 ( 53) | 1.5:1 |
| Design Limit | 223 (144) | 0.5:1 |

During low-flow conditions, it appears that the RWTP discharge will be equal to the flow of the Green-Duwamish in about 15 years. The state *Effluent Dilution Zone Guidelines*, which address the issue of dilution requirements, are included in Appendix I.

During periods of low flow, Green-Duwamish waters even as far up-river as the RWTP (river km 19.3) routinely reverse direction as the estuarine waters of Elliott Bay push into the lower river during high tide. A poorly-diluted block of river water combined with secondary wastewater is created each time flow reversal occurs. Succinctly, the river receives one wastewater dose as the waters pass the outfall during normal outflow; as high tide approaches, river velocity slows, stops, and begins to move upstream resulting in a second dose; then a third dose is received after high tide when the flow resumes downstream movement.

Flow reversal is an important factor which should be considered in dilution calculations concerning the Renton facility. Monitoring of drogue movements near the outfall during three different high tide cycles indicate the poor-dilution blocks may range from localized pooling during moderately high tides up to 0.5 kilometer (0.3 mile) or greater in length during periods of extensive tidal influx:

| Date | Flow | High Tide Heights (feet) | Distance Traveled Upstream (meters/feet) |
|---|---|---|---|
| 09/26 | 238 | 10.1 | 61/200 |
| 10/01 | 210 | 11.0 | 488/1600 |
| 11/15 | 260 | 10.9 | 122/400 |

Flow reversal appears to occur at tides above about 10 feet during low-flow conditions of about 300 cfs or less. About 75 percent of the Seattle tides during September and October 1979 exceeded 10 feet, ranging from 8.1 to 12.2 feet. Thus, flow reversal routinely occurs in the Green-Duwamish near the RWTP during low-flow conditions.

The percentage of wastewater in a number of samples collected near RWTP outfall during flow reversal was calculated using the following equation:

$$fe = \frac{Cs - Cu}{Ce - Cu}$$

where: fe = decimal fraction of effluent in the sample
Cs = concentration of a conservative tracer in the sample
Cu = concentration of the tracer upstream of the discharge
Ce = concentration of the tracer in the effluent

Specific conductivity was used as the conservative tracer. The percentage of effluent in poor-dilution blocks formed on two occasions, September 26 and November 15, ranged from about 25 percent to 100 percent depending on location (Figure 3).

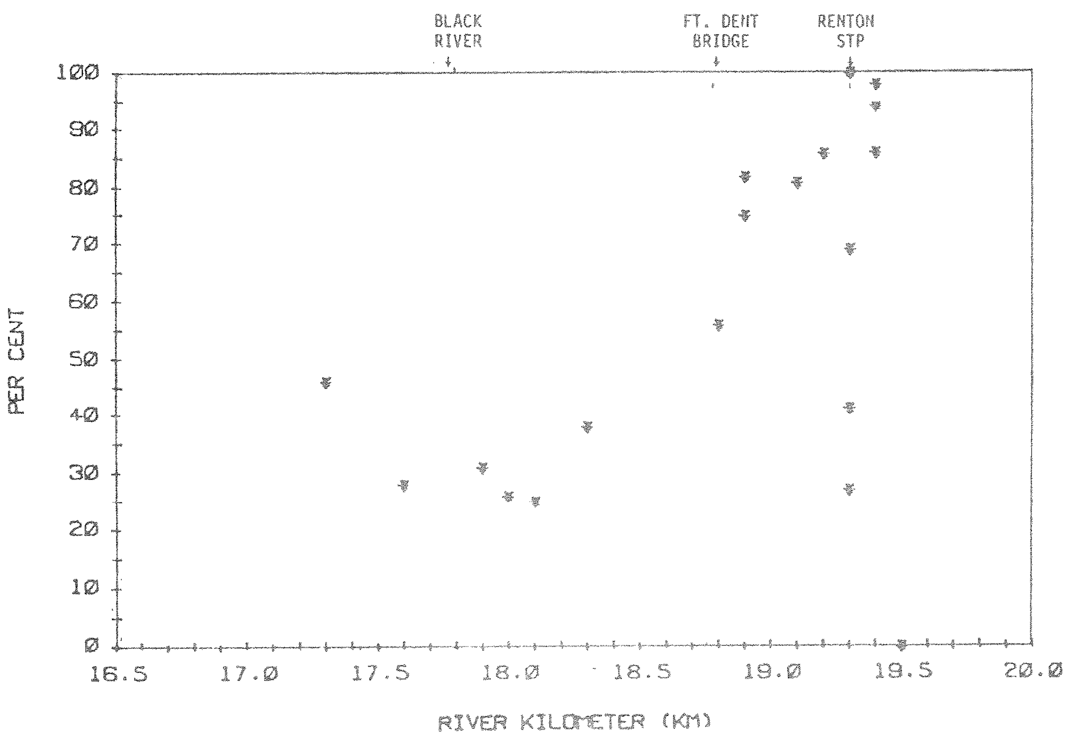


FIGURE 3. CALCULATED PERCENTAGE OF RWTP WASTEWATERS IN WATER SAMPLES COLLECTED IN THE GREEN-DUWAMISH RIVER NEAR THE RWTP OUTFALL DURING SEPTEMBER 18 AND NOVEMBER 15, 1979.

An average concentration of about 60 percent effluent would be expected assuming a 4:1 dilution ratio, three doses, and uniform mixing. Field conductivity transect sampling indicated vertical mixing occurs rapidly below the RWTP during regular stream outflow. Lateral mixing appeared to be complete by the time the effluent moved about 0.6 km (0.3 mile) below the RWTP at Fort Dent Bridge. Some layering occurs above the facility during flow reversal with the cooler stream waters moving below the warm surface waters until reaching the outfall.

The poor-dilution blocks of river/RWTP wastewaters represent average conditions that may exist in the river during summer low flow as the facility approaches the 144 MGD design capacity.

## Water Quality Assessment

The first 1.6 kilometers of the Green-Duwamish below the RWTP (effluent pipe to mouth of Black River) is classified Class A in the Washington State Water Quality Standards (1977) whereas waters below the Black River are classified Class B. Beneficial uses to be protected by these two classifications for both fresh and marine surface waters are given in Appendix A. A review of the water quality data by parameter follows:

### Temperature (°C)

Renton wastewater treatment plant increased the temperature of Green-Duwamish waters as shown below:

| Date Sampled | Temperature above RWTP | Temp. Renton WTP Effluent | Temp. 0.6 km below RWTP |
|---|---|---|---|
| 09/18/79 | 18.5 | 22.8 | 19.9 |
| 10/02/79 | 14.0 | 21.7 | 14.9 |

Ambient temperature above the RWTP exceeded the state Class A water quality standard on 9/18/79 (Figure 4). The standard states: "when conditions exceed 18° Celcius (freshwater) no temperature increase will be allowed which will raise the receiving water temperature by greater than 0.3° Celcius." A 1.4°C increase was observed after dilution (at Fort Dent Bridge). With the 10/02/79 survey, at which time the ambient standard was not exceeded, the $t = 28/(T + 7)$ formula which is the standard applicable in this case, resulted in a 0.75°C allowable increase. The standard was exceeded by a small margin (Figure 4). The Class B standard was not violated below the Black River during either survey.

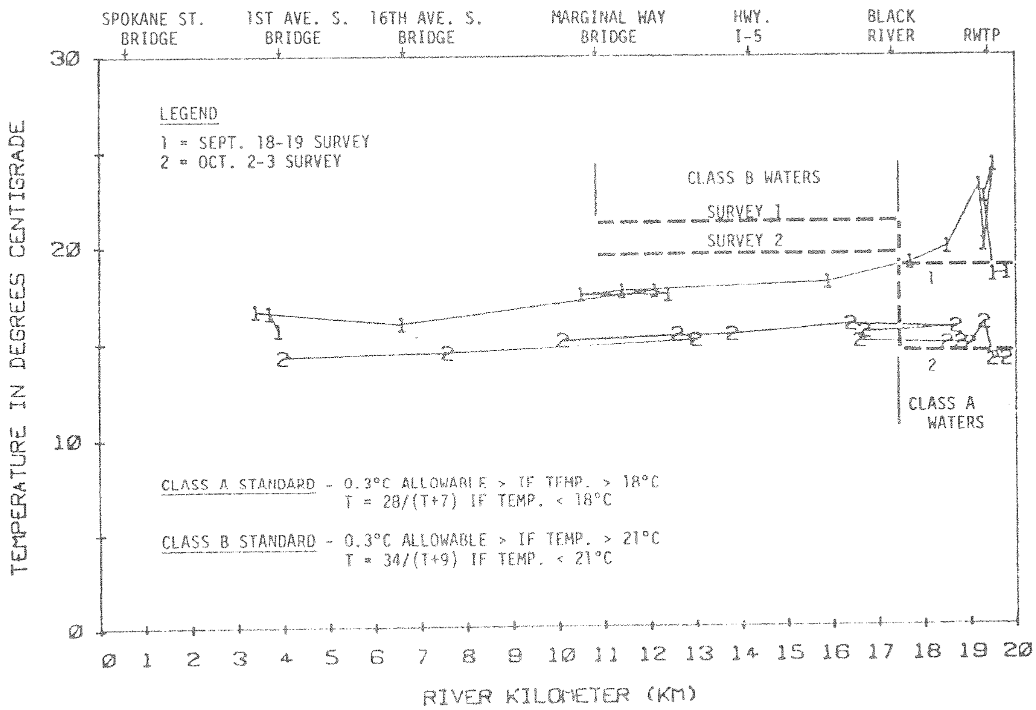


FIGURE 4. TEMPERATURE (°C) MEASUREMENTS COLLECTED ON THE GREEN-DUWAMISH RIVER DURING DOE 1979 TIME-OF-TRAVEL STUDY.

Temperature is an extremely important consideration in the case of the Green-Duwamish because, along with pH, it is a major factor in determining the percentage of ammonia present in the un-ionized form which is toxic to fish and other forms of aquatic life. Temperature also may contribute to other water quality problems. The lower Green-Duwamish appears to be particularly susceptible to temperature problems because much of the vegetation has been removed along the stream as it passes through the valley above.

## Specific Conductance (μmhos/cm)

Specific conductivity increased below the RWTP, stayed fairly constant until the river waters reached about river km 12.8 (R.M. 8), then increased substantially upon meeting entrained saline waters from Elliott Bay (Figure 5).

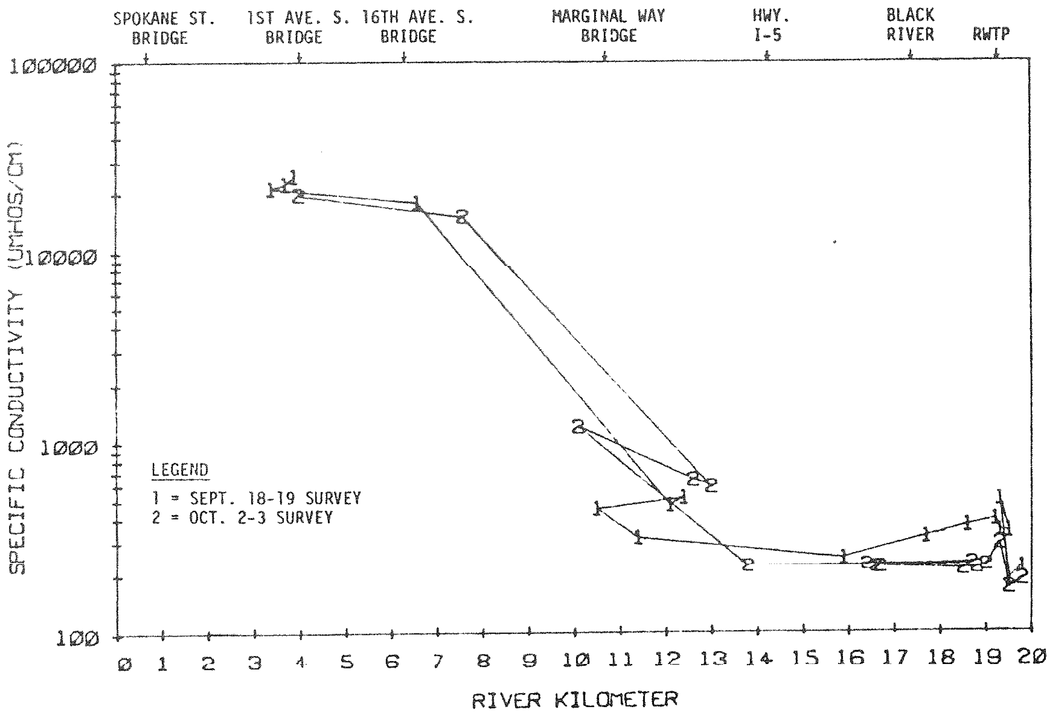


FIGURE 5. SPECIFIC CONDUCTIVITY MEASUREMENTS COLLECTED ON THE GREEN-DUWAMISH RIVER DURING DOE 1979 TIME-OF-TRAVEL STUDY.

## pH

pH was within acceptable limits at all stations, ranging from 6.9 to 7.6 throughout the study area. pH appeared to drop slightly near the RWTP outfall (Tables 2 and 3).

## Turbidity

Turbidity remained in the 2-to-5-NTU range throughout the study area during both time-of-travel drifts. RWTP appeared to have a slight impact (Tables 2 and 3).

## Total Alkalinity

Alkalinity, or buffering capacity, is a measure of the ability of components in water to elevate the pH of the water above about 4.5 (U.S. EPA, 1976). The U.S. EPA (1976) criterion for alkalinity is 20 mg/l for freshwater aquatic life except where natural conditions are less. Green-Duwamish waters exceeded this criterion at all stations during both time-of-travel surveys. The buffering capacity increased somewhat below the RWTP (Table 2).

## Dissolved Oxygen (D.O.)

Green-Duwamish waters were in violation of the state water quality standards during both surveys (Figure 6).

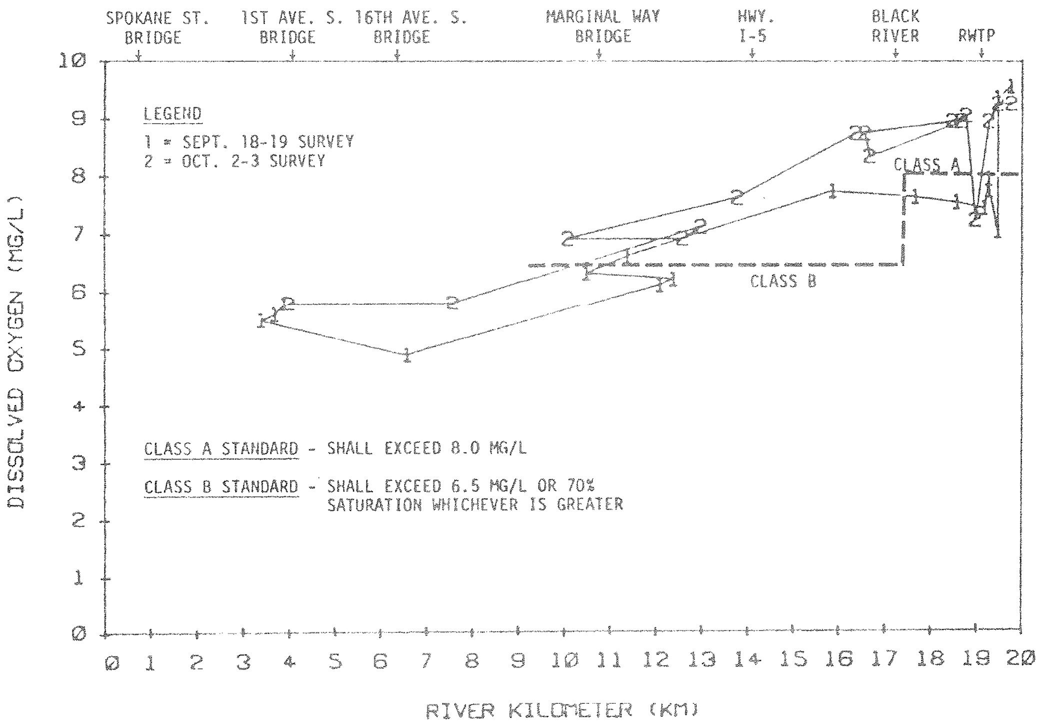


FIGURE 6. DISSOLVED OXYGEN CONCENTRATIONS OBSERVED DURING THE DOE 1979 GREEN-DUWAMISH RIVER TIME-OF-TRAVEL STUDY.

D.O. levels were below the 8.0 mg/l Class A standard at all stations along the 1.6-km (1-mile) section of stream between the RWTP and the Black River, during the September 18-19 survey. D.O. levels increased slightly then continued to gradually decline below Black River, reaching a low of 4.9 mg/l at river km 13.0 (R.M. 8). The Class B standard is 6.5 mg/l D.O. or 70 percent saturation, whichever is greater. The saturation requirement also was violated (Figure 7).

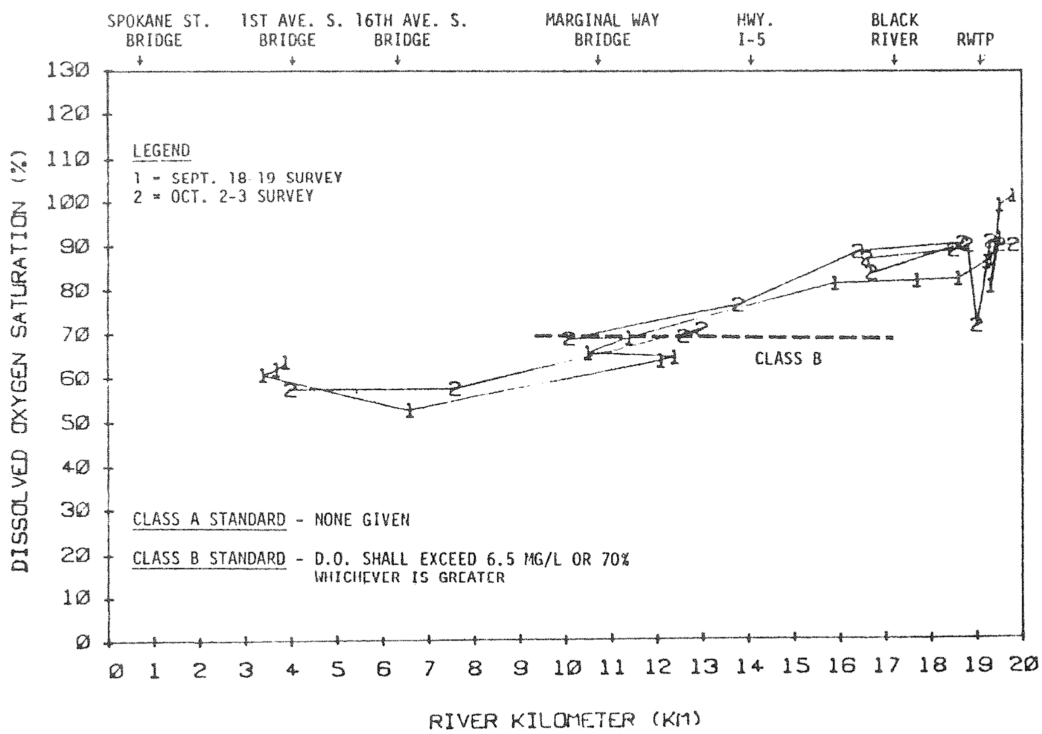


FIGURE 7. CALCULATED DISSOLVED OXYGEN SATURATION FOR SAMPLES COLLECTED DURING THE DOE 1979 GREEN-DUWAMISH RIVER TIME-OF-TRAVEL STUDY.

A D.O. violation also was noted below the RWTP during the October 2-3 survey, but not as evident as during the earlier survey.

A detailed analysis of factors contributing to the D.O. conditions in the river indicate the RWTP is a significant contributing factor (see Report No. 2).

## Total Residual Chlorine

The U.S. EPA Red Book criterion of .002 mg/l was exceeded for more than 3.2 km below the RWTP (Figure 8).

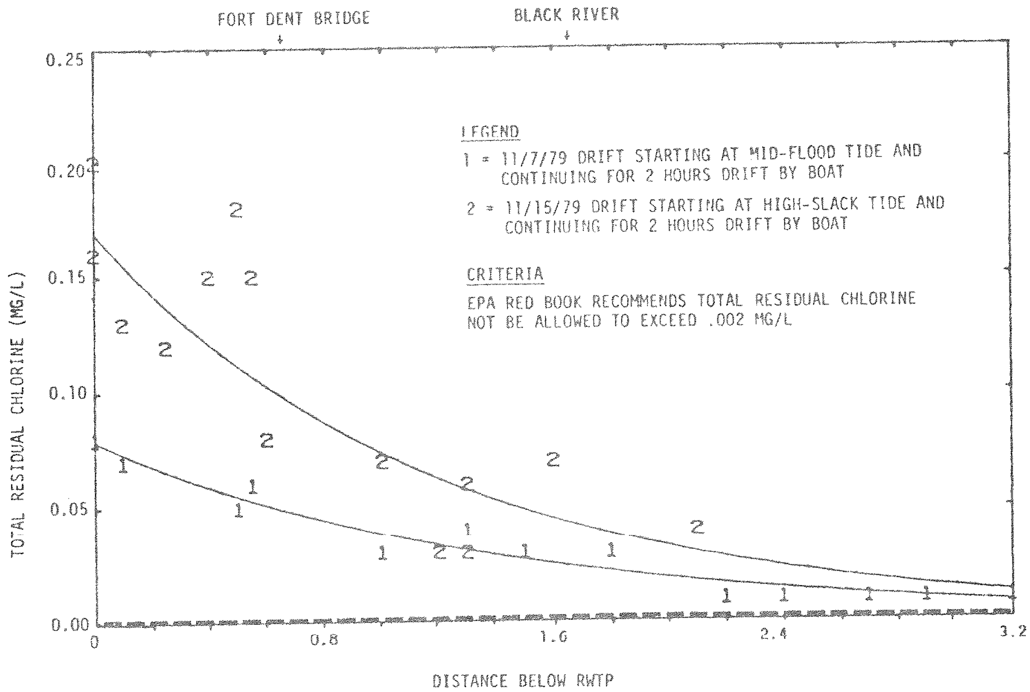


FIGURE 8. TOTAL RESIDUAL CHLORINE SAMPLING DATA (FERROUS DPD METHOD) COLLECTED ON THE GREEN-DUWAMISH RIVER DURING DOE 1979 TIME-OF-TRAVEL STUDY.

The total residual chlorine field measurements are given in Table 4. It is important to note that the field technique (ferrous DPD titrimetric method) was sensitive to .01 mg/l whereas the criterion is substantially lower at .002 mg/l.

Static acute toxicity bioassays performed by Buckley (1973) indicate residual chlorine was the principal toxicant to fish in RWTP effluent. Average 24- and 96-hour $IL_{50}$ concentrations of 0.23 and 0.20 mg/l were observed. In 1978 the RWTP went to dechlorination in an effort to minimize toxicity problems associated with chlorine, reducing the effluent from about 1.5 to about 0.25 mg/l. Based on the EPA criterion, residual chlorine levels appear to still exceed safe concentrations for some distance below the outfall even though the amount of chlorine discharged has been reduced considerably.

A consideration not addressed when field determinations of total residual chlorine are made is the relationship between chlorine and organic compounds which may exist in wastewater treatment plant effluents. Widespread concern is developing concerning the toxic and carcinogenic potential of some halogenated organic compounds that may be formed in waters which receive chlorinated wastewater. This is a developing issue with the RWTP.

BOD

$BOD_5$ was uniformly low throughout the study area (Tables 2 and 3).

Fecal Coliform Bacteria

The Class A criterion of 100 colonies/100 ml (median value) with not more than 10 percent of the samples exceeding 200 colonies/100 ml, was exceeded at some stations (Figure 9), but did not suggest a problem although the sample size was not large enough for statistical confirmation.

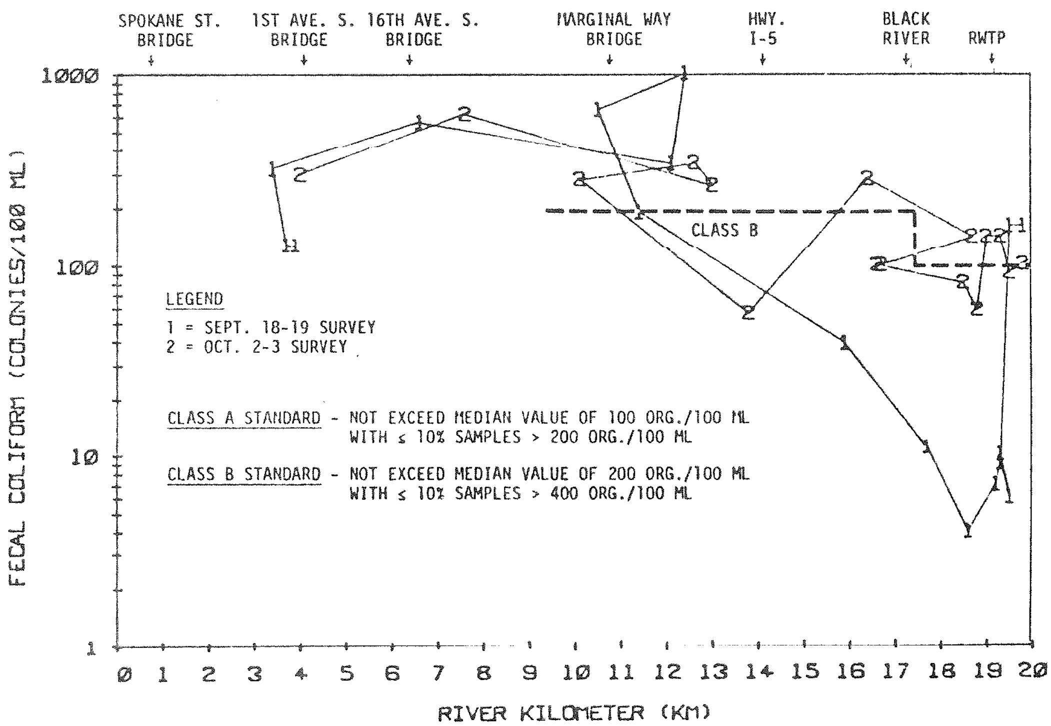


FIGURE 9. FECAL COLIFORM SAMPLING DATA COLLECTED ON THE GREEN-DUWAMISH RIVER DURING DOE 1979 TIME-OF-TRAVEL STUDY.

It is not known for certain if RWTP is a significant factor because the possibility of bacterial re-growth was not investigated.

The Class B standard of 200 organisms/100 ml, applicable to the lower 11 miles of river (below Black River), was generally exceeded during both surveys.

Nutrients

A detailed assessment of nitrification and its relationship to dissolved oxygen levels in the Green-Duwamish River below the RWTP is discussed in Report No. 2. This report addresses nutrient levels observed in the river and the relationship to water quality criteria or standards.

Renton WTP wastewaters contained 13 and 16 mg/l ammonia (as nitrogen) at the onset of the two sampling drifts (Tables 2 and 3). Although this is fairly typical of secondarily-treated wastewaters, it is considered high for the Green-Duwamish in light of the low dilution. The toxicity of aqueous solutions of ammonia is attributed almost entirely to the un-ionized ($NH_3$) form. U.S. EPA recommends that un-ionized ammonia should not exceed 0.02 mg/l to protect fresh-water aquatic life (EPA, 1976). This criterion appeared to be exceeded for up to 4 km (2-1/2 miles) below the RWTP (Figures 10 and 11).

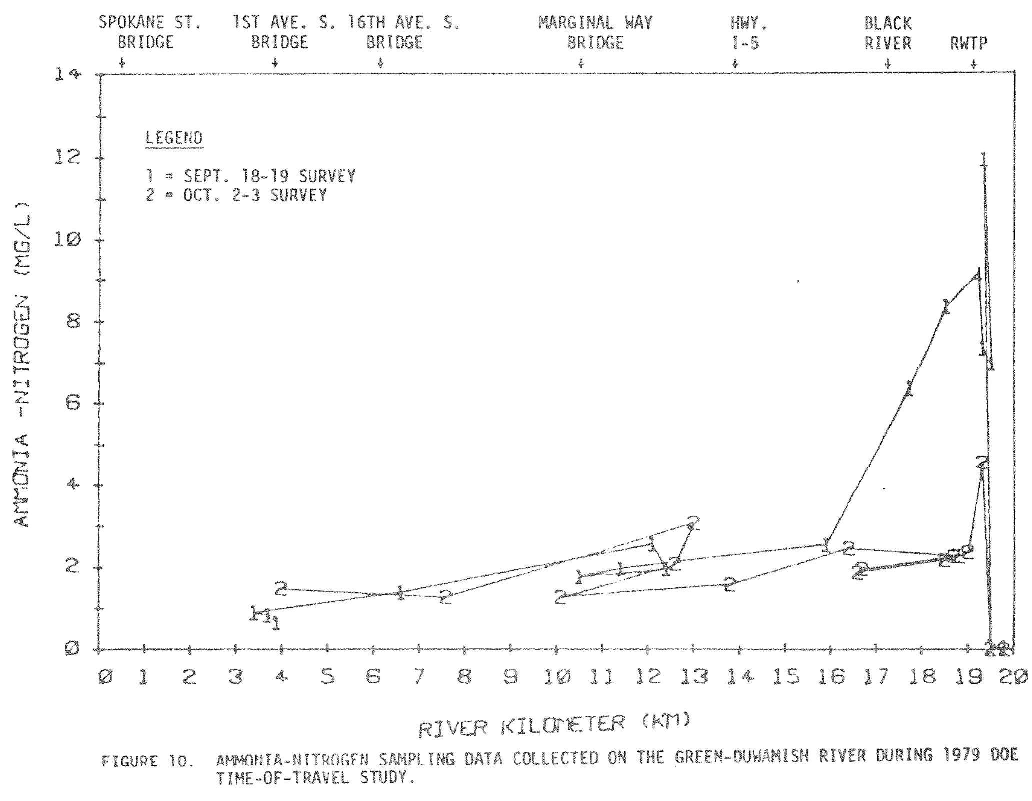


FIGURE 10. AMMONIA-NITROGEN SAMPLING DATA COLLECTED ON THE GREEN-DUWAMISH RIVER DURING 1979 DOE TIME-OF-TRAVEL STUDY.

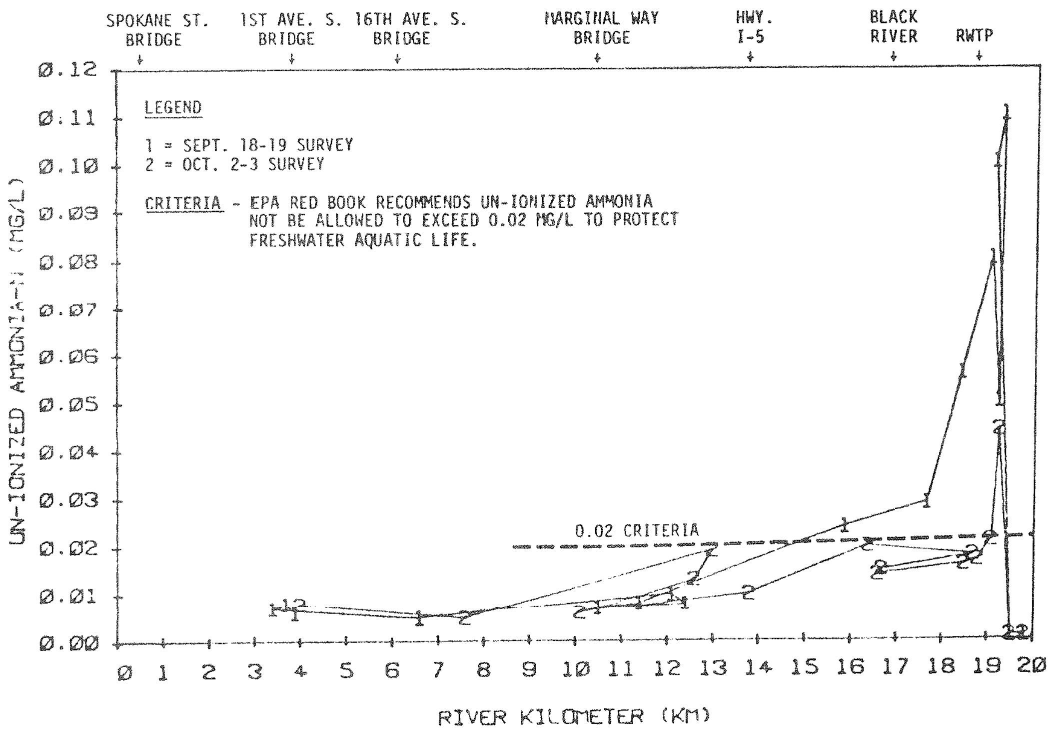


FIGURE 11. CALCULATED CONCENTRATIONS OF UN-IONIZED AMMONIA IN WATER QUALITY SAMPLES COLLECTED FROM THE GREEN-DUWAMISH RIVER DURING DOE 1979 TIME-OF-TRAVEL STUDY.

Ammonia discharged to a stream is converted to nitrates by Nitrosomonas and Nitrobacter bacteria, as follows:

| Nitrosomonas | lb. $O_2$ required per lb. N. oxidized | Formula |
|---|---|---|
| $NH_3 + 3/2O_2 \rightarrow NO_2^- + H_2O + H^+$ | 3.42 | 1 |
| and | | |
| Nitrobacter | | |
| $NO_2^- + 1/2O_2 \rightarrow NO_3^-$ | 1.14 | 2 |
| Total Reaction | | |
| $NH_3 + 2O_2 \rightarrow NO_3^- + H_2O + H^+$ | 4.57 | 3 |

Formula 1 above shows that nitrites are an intermediate product formed during nitrification. U.S. EPA recommends that nitrites should remain below 0.06 mg/l to protect salmonid fishes (U.S. EPA, 1976). As shown in Figure 12, nitrite-nitrogen steadily increased in the Green-Duwamish below the RWTP reaching the borderline range, in terms of toxicity, of 0.05 to 0.06 mg/l at about river km 12.6 (R.M. 8).

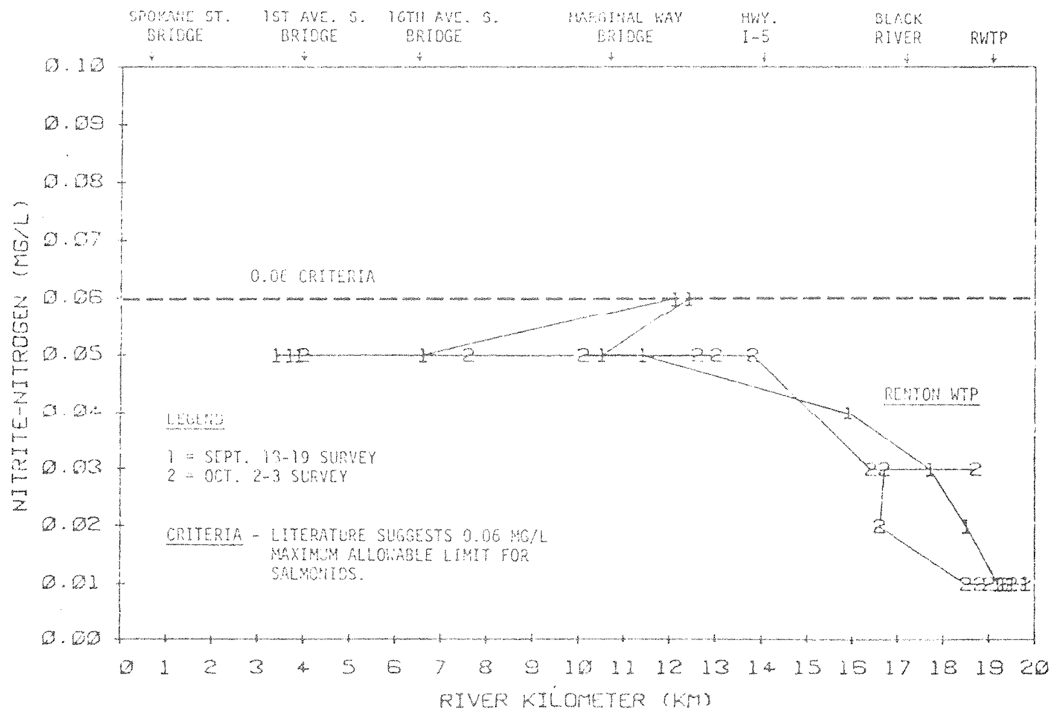


FIGURE 12. NITRITE-NITROGEN SAMPLING DATA COLLECTED ON THE GREEN-DUWAMISH RIVER DURING DOE 1979 TIME-OF-TRAVEL STUDY.

Nitrate and phosphate data are often compared to the algal bloom thresholds of 0.3 mg/l nitrate and 0.01 mg/l dissolved orthophosphate refered to by Klein (1959). These values address lakes and are applicable to streams only in some cases where the waters are sluggish and shallow. Even then, there are severe limitations in applying this criterion to the lower Green-Duwamish. Nitrates generally increased in the river below the RWTP exceeding the algal bloom criteria (Figure 13).

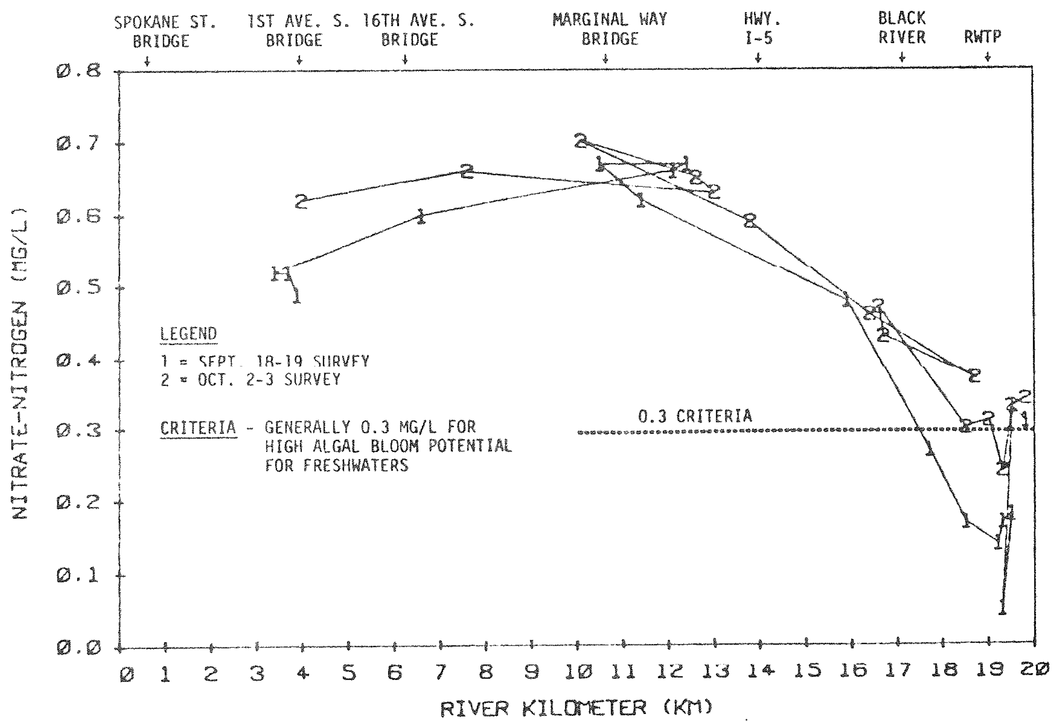


FIGURE 13. NITRATE-NITROGEN SAMPLING DATA COLLECTED ON THE GREEN-DUWAMISH RIVER DURING DOE 1979 TIME-OF-TRAVEL STUDY.

Phosphates also increased (Tables 2 and 3). The waters appeared to be enriched in terms of these two constituents. Based on the chlorophyll a and pheophytin a concentrations observed, algal population appeared to be generally healthy, but bloom conditions did not exist during either time-of-travel drift (Tables 2 and 3). Other possible limiting factors to be considered may include light, temperature, hydrology, detention time, attached algae, or aquatic macrophytes, or some inhibitory constituent(s) in the RWTP wastewaters or ambient river waters.

## Total Suspended Solids

Total suspended solids were low throughout the study area during both time-of-travel surveys (Tables 2 and 3).

## Metals and Other Priority Pollutants

Seattle METRO was in the early stages of planning a comprehensive pretreatment and toxicant study at the time of the DOE time-of-travel study. Since the Green/Duwamish and Renton WTP are included in the METRO assessment (which is in progress as of this writing), metals and other toxics were not addressed in the DOE effort. This aspect must be given consideration in any overall analysis of water quality in the lower Green-Duwamish River.

Summary and Comments

A summary of water quality problems associated, at least in part, with RWTP observed in the Green-Duwamish River during the two time-of-travel surveys, September 18-19, and October 2-3, 1979, follows:

1. Dilution - At 4:1 and 4.4:1, the stream-to-effluent dilution ratios were substantially below the 20:1 minimum recommended in the state effluent dilution zone guidelines. The guidelines are based on the 7-day, 10-year, low flow. If these conditions had prevailed at the time of the survey, a 1.8:1 ratio would have existed. Assuming a 1.7 MGD annual growth rate (dry-weather flow) for the RWTP, the discharge will be equal to the total river flow in about 15 years.

2. Flow Reversal - During low-flow conditions, the Green-Duwamish near RWTP routinely changes direction in response to the inflow of tidal waters from Elliott Bay moving into the lower river. Poorly-diluted blocks of river and wastewater form during tides above about 10 feet. Tides at or above this level appear about 75 percent of the time when river flows are less than 300 cfs. The blocks may range from localized pooling up to 0.5 km or more in length, depending on tide height. The percent wastewaters in these blocks at times may exceed 60 percent.

3. Temperature - The state water quality standard for Class A waters was exceeded during both surveys. Although not apparently substantial (1.4 and 0.75 °C), the violations are important considerations because: (A) Ambient temperatures approached the upper limit for some salmonids during the September survey; (B) temperature and pH are the principal factors in determining the percent of ammonia in aqueous solutions present in the toxic un-ionized form. As these two parameters increase, the amount of un-ionized ammonia present increases rapidly; and (C) thermal shock can adversely affect salmonids, at least indirectly, even where a temperature change of only 2°C is involved.

4. Dissolved Oxygen - D.O. concentrations below the RWTP declined to below the state water quality standard of 8.0 mg/l (Class A waters) and continued to decline slowly until reaching 4.9 mg/l (Class B waters standard = 6.5 mg/l) at river km 12.8, during the September survey. A less evident violation was observed during October.

5. Total Residual Chlorine - Dechlorination was implemented at RWTP in 1978, reducing residual chlorine concentrations in the final effluent from about 1.5 to 0.25 mg/l. Data collected from the river below the outfall indicate the outfall continues to exceed safe levels. U.S. EPA recommends that total residual chlorine should not be allowed to exceed .002 mg/l. This criterion appeared to be exceeded for over 3.2 km (2 miles) below the outfall.

6. Un-ionized Ammonia - U.S. EPA recommends that un-ionized ammonia should not exceed 0.02 mg/l to protect freshwater aquatic life. This criterion appeared to be exceeded for about 4 km (2-1/2 miles) below the RWTP.

7. Nitrite - U.S. EPA recommends that nitrites not be allowed to exceed 0.06 mg/l to protect salmonid fishes. Nitrites steadily increased below RWTP reaching borderline concentrations of 0.05 to 0.06 mg/l in the lower river.

At the current dry-weather discharge of approximately 36 MGD secondary-treated wastewaters, Renton WTP appears to be exceeding the assimilative capacity of the Green-Duwamish River during low-flow periods. The stream has some serious water quality problems if state effluent guidelines, EPA water quality criteria, and state water quality standards are used as indicators of condition. Adverse stream conditions associated with the RWTP are expected to become more severe if the plant continues to treat greater quantities of wastewater and approaches the 144 MGD ultimate site capacity. Unless a major change in waste handling or treatment occurs, it appears that the Green-Duwamish will essentially evolve into a wastewater pipeline between Renton and Elliott Bay within about 20 years.

As previously stated, the state water quality standards classify the 1.6-kilometer (one river mile) section between the RWTP and the Black River as Class A, whereas the river between this point and Elliott Bay is classified as Class B. Presently the river below the Black River is physically quite similar and used for essentially the same purposes as above. It would appear that the Class A designation should be reviewed and could logically be moved downstream to the upper end of the Duwamish dredged waterway.

It appears that the stream water quality monitoring network on the lower Green-Duwamish River maintained by METRO should be altered to better track the effects of the RWTP. A new station at Fort Dent Bridge (0.6 km below the plant) would seem appropriate. Sampling data at this location would not only provide an improved indication of stream impacts, but also be of value in monitoring immediate river response to any operational changes that may be undertaken at the plant to improve effluent quality.

Some additional studies are needed on the river to better characterize stream conditions as they relate to the Renton WTP. Information on fishes which inhabit or may otherwise utilize the lower Green-Duwamish during critical summer low-flow periods is very limited. Some difficulty was met in attempting to remain with the same block of stream water between the RWTP and the river mouth. Fixed stations at selected sites sampled frequently over a 24-hour period would provide a clearer picture of changes the poor-dilution blocks undergo while moving down river. In situ bioassays may be of benefit in determining actual benefits derived from dechlorination at the RWTP.

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Table 2. Summary of Water Quality Data Collected by DOE during Green-Duwamish River Time-of-Travel Study, Starting at High-Slack Tide near Renton Wastewater Treatment Plant (RWTP) Outfall, September 18-19, 1979.

| Station | Location | Time | Time of Travel | Flow cfs | Flow MGD | Temp. (°C) | S. Cond. (µmhos/cm) | pH | Turb. (NTU) | T. Alk. (as $CaCO_3$) (mg/l) | D.O. (mg/l) | D.O. Sat. (%) | Total Chlorine (mg/l) | BOD (mg/l) | Fecal Coli. (Col/100 ml) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 19.8 | Control 0.5 km abv. Renton Wastewater Treatment Plant (RWTP) Outfall | 1530 | --- | --- | --- | 13.5 | 220 | 7.6 | 2 | 61 | 9.5 | 100.6 | --- | <2 | 160 |
| 19.5 | Control 0.2 km above RWTP Outfall | 1510 | --- | 274 | 177 | 18.4 | 188 | 7.6 | 2 | 57 | 9.3 | 98.3 | --- | 2 | 160 |
| Drogues start upstream movement at 1515 | | | | | | | | | | | | | | | |
| WTP | RWTP final effluent | 1410 | --- | 63 | 44 | 22.8 | 525 | 7.3 | 5 | 120 | 8.4 | 96.5 | 0.23 2/ | 6 | 100 |
| 19.3 | River water from boil at RWTP Outfall | 1610 | --- | 342 | 221 | 22.5 | 499 | 7.2 | 3 | 110 | 7.0 | 80.1 | --- | 4 | 9 |
| 19.5 | 0.2 km above RWTP Outfall 1/ | 1640 | --- | --- | --- | 24.2 | 339 | 7.3 | 3 | 87 | 7.7 | 90.8 | --- | 2 | 6 |
| Drogues stop upstream movement at 1645 | | | | | | | | | | | | | | | |
| 19.3 | About 30 m above RWTP Outfall | 1720 | --- | --- | --- | 20.0 | 344 | 7.3 | 4 | 89 | 7.9 | 86.2 | --- | 3 | 10 |
| Drogues pass outfall at 1726 heading downstream | | | | | | | | | | | | | | | |
| 19.2 | At first bend about 250 m below RWTP Outfall | 1741 | :15 | --- | --- | 23.1 | 391 | 7.2 | 4 | 93 | 7.4 | 85.6 | --- | -- | 7 |
| 18.6 | About 0.7 km below RWTP Outfall, just below Fort Dent Bridge | 1811 | :45 | --- | --- | 19.9 | 365 | 7.2 | 3 | 93 | 7.5 | 81.5 | --- | 4 | 4 |
| 17.7 | About 1.6 km below RWTP Outfall at mouth of Black River | 1850 | 1:30 | --- | --- | 19.1 | 320 | 7.3 | 3 | 87 | 7.6 | 81.5 | --- | -- | 11 |
| 15.9 | About 3.4 km below RWTP Outfall at North end of Foster Golf Course | 2026 | 3:00 | --- | --- | 18.1 | 248 | 7.4 | 3 | 71 | 7.7 | 80.9 | --- | 4 | 39 |
| 11.4 | About 7.9 km below RWTP Outfall, at first bend above Marginal Way Bridge | 2226 | 5:00 | --- | --- | 17.7 | 319 | 7.3 | 4 | 65 | 6.6 | 68.8 | --- | 4 | 190 |

Table 2. - Continued

| Station | Location | Time | Time of Travel | Flow cfs | Flow MGD | Temp. (°C) | S. Cond. (μmhos/cm) | pH | Turb. (NTU) | T. Alk. (as $CaCO_3$) (mg/l) | D.O. (mg/l) | D.O. Sat. (%) | Total Chlorine (mg/l) | BOD (mg/l) | Fecal Coli. (Col/100 ml) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Drogues stop downstream movement at 2357 and start upstream movement at 0015 | | | | | | | | | | | | | | | |
| 10.5 | About 8.9 km below RWTP Outfall, just below Old Highway 99 Bridge | 0026 | 7:00 | --- | --- | 17.5 | 453 | 7.3 | 3 | 65 | 6.3 | 65.5 | --- | 3 | 650 |
| 12.4 | About 6.9 km below RWTP Outfall, near S. 122nd St. | 0226 | 9:00 | --- | --- | 17.5 | 516 | 7.3 | 3 | 67 | 6.2 | 64.4 | --- | -- | 1,000 |
| Drogues stop upstream movement at 0400 and begin downstream movement at 0430 | | | | | | | | | | | | | | | |
| 12.1 | About 7.2 km below RWTP Outfall, just above Old Macadam Road Bridge (42nd Avenue South) | 0526 | 12:00 | --- | --- | 17.7 | 472 | 7.2 | 2 | 71 | 6.1 | 63.6 | --- | 4 | 340 |
| 6.6 | About 12.7 km below RWTP Outfall, at 1st bend above 16th Avenue South Bridge | 0826 | 15:00 | --- | --- | 16.0 | 18,000 | 7.3 | 2 | 81 | 4.9 | 52.7 | --- | -- | 560 |
| 3.4 | About 15.9 km below RWTP Outfall, near Slip No. 2 just below 1st Ave. So. Br. | 1126 | 18:00 | --- | --- | 16.7 | 21,300 | 7.2 | 2 | 86 | 5.5 | 60.8 | --- | -- | 320 |
| Drogues begin upstream movement at 1220 | | | | | | | | | | | | | | | |
| 3.7 | About 15.6 km below RWTP Outfall, just above 1st Avenue South Bridge | 1426 | 21:00 | --- | --- | 16.6 | 22,600 | 7.4 | 2 | 93 | 5.6 | 62.1 | --- | -- | 130 |
| 3.9 | About 15.5 km below RWTP Outfall, just above 1st Avenue South Bridge | 1726 | 24:00 | --- | --- | 15.7 | 24,800 | 7.4 | 4 | 86 | 5.8 | 63.7 | --- | -- | 130 |

1/ Moved upstream to same location as lower control station.

2/ From Renton WTP self-monitoring data.

"<" = "less than"

Table 2. - Continued

| Station | Location | Nitrate-N (mg/l) | Nitrite-N (mg/l) | Ammonia-N (mg/l) | Un-ionized Ammonia (mg/l)[3/] | Total Kjeldahl Nitrogen (mg/l) | Ortho-Phosphate-P (mg/l)[4/] | Total Phosphate-P (mg/l) | Total Suspended Solids (mg/l) | Chloro-phyll a (mg/l) | Pheo-phytin a (mg/l) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 19.8 | Control 0.5 km abv. Renton Wastewater Treatment Plant (RWTP) Outfall | .31 | <.01 | .06 | .001 | .28 | .08 | .06 | 2 | --- | --- |
| 19.5 | Control 0.2 km above RWTP Outfall | .33 | <.01 | .10 | <.001 | .49 | .06 | .05 | 4 | 3.0 | 0.3 |
| Drogues start upstream movement at 1515 | | | | | | | | | | | |
| WTP | RWTP final effluent | <.20 | <.20 | 13.0 | .067 | 17 | 3.0 | 3.0 | 4 | 1.6 | 0.6 |
| 19.3 | River water from boil at RWTP Outfall | .05 | .01 | 12.0 | .100 | 15 | 2.8 | 2.6 | 4 | 2.4 | 0.7 |
| 19.5 | 0.2 km above RWTP Outfall[1/] | .18 | .01 | 7.0 | .110 | 10 | 1.9 | 1.8 | 3 | 1.8 | 1.3 |
| Drogues stop upstream movement at 1645 | | | | | | | | | | | |
| 19.3 | About 30 m above RWTP Outfall | .17 | .01 | 7.4 | .050 | 9.0 | 1.7 | 1.9 | 4 | 2.7 | 0.6 |
| Drogues pass outfall at 1726 heading downstream | | | | | | | | | | | |
| 19.2 | At first bend about 250 m below RWTP Outfall | .14 | .01 | 9.2 | .080 | 11 | 1.8 | 2.0 | 2 | 1.8 | 1.9 |
| 18.6 | About 0.7 km below RWTP Outfall, just below Fort Dent Bridge | .17 | .02 | 8.4 | .056 | 12 | 1.8 | 2.0 | 4 | 1.6 | 2.0 |
| 17.7 | About 1.6 km below RWTP Outfall at mouth of Black River | .27 | .03 | 6.4 | .029 | -- | 1.3 | .80 | 4 | --- | --- |
| 15.9 | About 3.4 km below RWTP Outfall at North end of Foster Golf Course | .48 | .04 | 2.6 | .024 | 3.0 | .54 | .60 | 6 | 4.3 | 1.3 |
| 11.4 | About 7.9 km below RWTP Outfall, at first bend above Marginal Way Bridge | .62 | .05 | 2.0 | .008 | -- | .41 | .60 | 7 | --- | --- |

Table 2. - Continued

| Station | Location | Nitrate-N (mg/l) | Nitrite-N (mg/l) | Ammonia-N (mg/l) | Un-ionized Ammonia (mg/l)3/ | Total Kjeldahl Nitrogen (mg/l) | Ortho-Phosphate-P (mg/l)4/ | Total Phosphate-P (mg/l) | Total Suspended Solids (mg/l) | Chlorophyll a (mg/l) | Pheophytin a (mg/l) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Drogues stop downstream movement at 2357 and start upstream movement at 0015 | | | | | | | | | | | |
| 10.5 | About 8.9 km below RWTP Outfall, just below Old Highway 99 Bridge | .67 | .05 | 1.8 | .007 | 2.5 | .36 | .70 | 4 | 3.3 | 0.1 |
| 12.4 | About 6.9 km below RWTP Outfall, near S. 122nd St. | .67 | .05 | 2.0 | .008 | -- | .41 | .80 | 6 | --- | --- |
| Drogues stop upstream movement at 0400 and begin downstream movement at 0430 | | | | | | | | | | | |
| 12.1 | About 7.2 km below RWTP Outfall, just above Old Macadam Road Bridge (42nd Avenue South) | .66 | .05 | 2.6 | .010 | 4.0 | .57 | .70 | 5 | 3.4 | 0.1 |
| 6.6 | About 12.7 km below RWTP Outfall, at 1st bend above 16th Avenue South Bridge | .60 | .05 | 1.4 | .005 | -- | .34 | .60 | 9 | --- | --- |
| 3.4 | About 15.9 km below RWTP Outfall, near Slip No. 2 just below 1st Ave. So. Br. | .52 | .05 | .90 | .007 | 5.5 | .36 | .34 | 6 | 2.4 | 0.1 |
| Drogues begin upstream movement at 1220 | | | | | | | | | | | |
| 3.7 | About 15.6 km below RWTP Outfall, just above 1st Avenue South Bridge | .52 | .05 | .84 | .008 | -- | .34 | .40 | 2 | --- | --- |
| 3.9 | About 15.5 km below RWTP Outfall, just above 1st Avenue South Bridge | .49 | .05 | .68 | .006 | -- | .29 | .30 | 5 | 2.7 | 0.2 |

1/ Moved upstream to same location as lower control station.

3/ Calculated values.

4/ **Ortho-phosphates exceeded total phosphates due to unknown factors.**

"<" = "less than"

Table 3. Summary of Water Quality Data Collected by DOE during Green-Duwamish River Time-of-Travel Study, Starting at Low Tide near Renton WTP Outfall, October 2-3, 1979.

| Station | Location | Time | Time of Travel | Flow cfs | Flow MGD | Temp. (°C) | S. Cond. (μmhos/cm) | pH | Turb. (NTU) | D.O. (mg/l) | D.O. Sat. (%) | Total Chlorine (mg/l) | COD (mg/l) | Fecal Coli. w/o Thio. (Col/100 ml) | Fecal Coli. w/Thio. (Col/100 ml) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 19.8 | Control 0.5 km above Renton Wastewater Treatment Plant (RWTP) Outfall | 0945 | --- | --- | --- | 14.0 | 186 | 7.5 | 3 | 9.2 | 89.4 | --- | <4 | 160 | 100 |
| 19.5 | Control 0.2 km above RWTP Outfall | 0930 | --- | 210 | 136 | 14.0 | 169 | 7.5 | 2 | 9.2 | 89.4 | --- | -- | 100 | 90 |
| WTP | RWTP Final Effluent | 1030 | --- | 48 | 31 | 21.7 | 500[1/] | 6.9 | 9 | 7.0 | 79.8 | 0.24[2/] | 95 | 18 | 220 |
| 19.3 | 15 m below RWTP Outfall | 1015 | --- | 258 | 167 | 15.9 | 291 | 7.4 | 4 | 8.9 | 90.1 | --- | 28 | 14 | 140 |
| Drogues placed near outfall at 1025 | | | | | | | | | | | | | | | |
| 19.0 | About 300 m below Outfall between 1st bend and Fort Dent Bridge | 1040 | :15 | --- | --- | 14.8 | 224 | 7.4 | 4 | 7.2 | 71.2 | --- | -- | 35 | 140 |
| 18.8 | About 500 m below RWTP Outfall, immed. above Fort Dent Bridge | 1055 | :30 | --- | --- | 14.9 | 216 | 7.3 | 4 | 9.0 | 89.2 | --- | 16 | 120 | 58 |
| 18.5 | About 0.8 km below Outfall, just below 1st bend below Fort Dent Bridge | 1110 | :45 | --- | --- | 14.9 | 213 | 7.3 | 3 | 8.9 | 88.2 | --- | -- | 62 | 80 |
| 16.6 | About 2.7 km below RWTP Outfall, above Foster Golf Course Footbridge | 1155 | 1:30 | --- | --- | 15.0 | 220 | 7.3 | 4 | 8.7 | 86.4 | --- | 20 | 94 | 100 |
| Drogues stop downstream movement at 1215 and begin upstream movement at 1250 | | | | | | | | | | | | | | | |
| 16.7 | About 2.6 km below RWTP Outfall at Foster Golf Course Footbridge | 1325 | 3:00 | --- | --- | 15.5 | 220 | 7.3 | 4 | 8.3 | 83.3 | --- | -- | 160 | 100 |
| 18.7 | About 0.6 km below RWTP at Fort Dent Bridge | 1525 | 5:00 | --- | --- | 15.7 | 230 | 7.3 | 5 | 8.9 | 89.7 | --- | 16 | 160 | 140 |

Table 3. - Continued

| Station | Location | Time | Time of Travel | Flow cfs | Flow MGD | Temp. (°C) | S. Cond. (µmhos/cm) | pH | Turb. (NTU) | D.O. (mg/l) | D.O. Sat. (%) | Total Chlorine (mg/l) | COD (mg/l) | Fecal Coli. w/o Thio. (Col/100 ml) | Fecal Coli. w/Thio. (Col/100 ml) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Drogues stop upstream movement at 1530 and begin downstream movement at 1555 | | | | | | | | | | | | | | | |
| 16.4 | About 2.9 km below RWTP, very near Station 7 | 1725 | 7:00 | --- | --- | 15.9 | 226 | 7.3 | 4 | 8.7 | 88.1 | --- | -- | 380 | 280 |
| 13.8 | About 5.5 km below RWTP below I-5 freeway Bridge | 1925 | 9:00 | --- | --- | 15.4 | 223 | 7.2 | 3 | 7.6 | 76.1 | --- | 12 | 54 | 56 |
| Drogues stop at 2130 | | | | | | | | | | | | | | | |
| 10.1 | About 9.1 km below RWTP, near Drive-in Theatre below Old U.S. Hwy. 99 Bridge (Pacific Highway South) | 2225 | 12:00 | --- | --- | 15.1 | 1,210 | 7.1 | 2 | 6.9 | 68.7 | --- | -- | 340 | 280 |
| Drogues begin upstream movement at 2250 | | | | | | | | | | | | | | | |
| 12.6 | About 6.7 km below RWTP, just below 42nd Ave. South (Allentown) Bridge | 0125 | 15:00 | --- | --- | 15.4 | 634 | 7.2 | 3 | 6.9 | 69.1 | --- | 14 | 350 | 340 |
| Drogues stop upstream movement at 0300 and begin downstream movement at 0335 | | | | | | | | | | | | | | | |
| 13.0 | About 6.2 km below RWTP, above 42nd Ave. S. Bridge | 0425 | 18:00 | --- | --- | 15.1 | 585 | 7.2 | 3 | 7.1 | 70.7 | --- | -- | 250 | 260 |
| 7.6 | About 11.7 km below RWTP, near 16th Ave. S. Bridge | 0725 | 21:00 | --- | --- | 14.5 | 15,200 | 7.1 | 3 | 5.8 | 57.5 | --- | 320 | 410 | 620 |
| 4.0 | About 15.2 km below RWTP at 1st Ave. S. Bridge (Hwy. 509) | 0925 | 23:00 | --- | --- | 14.3 | 19,800 | 7.2 | 3 | 5.8 | 57.4 | --- | -- | 330 | 300 |

1/ Estimate based on specific conductance in river above and below Renton WTP Outfall.

2/ From Renton WTP self-monitoring data.

"<" = "less than"

Table 3. - Continued

| Station | Location | Nitrate-N (mg/l) | Nitrite-N (mg/l) | Ammonia-N (mg/l) | Un-ionized Ammonia (mg/l) | Total Kjeldahl Nitrogen (mg/l) | Ortho-Phosphate-P (mg/l)[3/] | Total Phosphate-P (mg/l) | Total Solids (mg/l) | Total Non-Vol. Solids (mg/l) | Total Susp. Solids (mg/l) | Total Susp. Non-Vol. Solids (mg/l) | Chlorophyll a (mg/m³) | Pheophytin a (mg/m³) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 19.8 | Control 0.5 km above Renton Wastewater Treatment Plant (RWTP) Outfall | .34 | <.01 | .04 | <.001 | .19 | .04 | .01 | 110 | 79 | 10 | 3 | 2.9 | 2.4 |
| 19.5 | Control 0.2 km above RWTP Outfall | .33 | <.01 | .03 | <.001 | --- | .04 | .02 | --- | --- | -- | -- | --- | --- |
| WTP | RWTP Final Effluent | <.20 | <.20 | 16.0 | .076 | 21 | 5.4 | 5.1 | 300 | 230 | 29 | 2 | --- | --- |
| 19.3 | 15 m below RWTP Outfall | .24 | <.01 | 4.6 | .044 | --- | 1.6 | 1.0 | 180 | 130 | 10 | 3 | 2.5 | 1.3 |
| Drogues placed near outfall at 1025 | | | | | | | | | | | | | | |
| 19.0 | About 300 m below Outfall between 1st bend and Fort Dent Bridge | .31 | <.01 | 2.4 | .021 | --- | .90 | .50 | --- | --- | -- | -- | --- | --- |
| 18.8 | About 500 m below RWTP Outfall, immed. above Fort Dent Bridge | --- | <.01 | 2.3 | .017 | --- | .80 | .50 | 160 | 120 | 10 | 10 | 3.9 | 2.5 |
| 18.5 | About 0.8 km below Outfall, just below 1st bend below Fort Dent Bridge | .30 | <.01 | 2.2 | .016 | --- | .70 | .50 | --- | --- | -- | -- | --- | --- |
| 16.6 | About 2.7 km below RWTP Outfall, above Foster Golf Course Footbridge | .47 | .02 | 1.9 | .014 | --- | .70 | .50 | 150 | 110 | 8 | 4 | 4.7 | 0.6 |
| Drogues stop downstream movement at 1215 and begin upstream movement at 1250 | | | | | | | | | | | | | | |
| 16.7 | About 2.6 km below RWTP Outfall at Foster Golf Course Footbridge | .43 | .03 | 2.0 | .015 | --- | .70 | .50 | --- | --- | -- | -- | --- | --- |
| 18.7 | About 0.6 km below RWTP at Fort Dent Bridge | .37 | .03 | 2.3 | .018 | 3.4 | 1.0 | .60 | 150 | 120 | 5 | 4 | 3.8 | 1.0 |

Table 3. - Continued

| Station | Location | Nitrate-N (mg/l) | Nitrite-N (mg/l) | Ammonia-N (mg/l) | Un-ionized Ammonia (mg/l) | Total Kjeldahl Nitrogen (mg/l) | Ortho-Phosphate-P (mg/l)[3/] | Total Phosphate-P (mg/l) | Total Solids (mg/l) | Total Non-Vol. Solids (mg/l) | Total Susp. Solids (mg/l) | Total Susp. Non-Vol. Solids (mg/l) | Chlorophyll a (mg/m³) | Pheophytin a (mg/m³) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Drogues stop upstream movement at 1530 and begin downstream movement at 1555 | | | | | | | | | | | | | | |
| 16.4 | About 2.9 km below RWTP, very near Station 7 | .46 | .03 | 2.5 | .020 | --- | 9.0 | .50 | --- | --- | -- | -- | --- | --- |
| 13.8 | About 5.5 km below RWTP below I-5 freeway Bridge | .59 | .05 | 1.5 | .010 | 1.8 | .60 | .40 | 150 | 100 | 11 | 5 | 1.8 | 2.4 |
| Drogues stop at 2130 | | | | | | | | | | | | | | |
| 10.1 | About 9.1 km below RWTP, near Drive-in Theatre below Old U.S. Hwy. 99 Bridge (Pacific Highway South) | .70 | .05 | 1.3 | .006 | --- | .50 | .20 | --- | --- | -- | -- | --- | --- |
| Drogues begin upstream movement at 2250 | | | | | | | | | | | | | | |
| 12.6 | About 6.7 km below RWTP, just below 42nd Ave. South (Allentown) Bridge | .65 | .05 | 2.1 | .013 | 3.1 | .80 | .70 | 350 | 290 | 6 | 6 | 1.7 | 2.4 |
| Drogues stop upstream movement at 0300 and begin downstream movement at 0335 | | | | | | | | | | | | | | |
| 13.0 | About 6.2 km below RWTP, above 42nd Ave. S. Bridge | .63 | .05 | 3.1 | .019 | --- | 1.1 | 1.0 | --- | --- | -- | -- | --- | --- |
| 7.6 | About 11.7 km below RWTP, near 16th Ave. S. Bridge | .66 | .05 | 1.3 | .005 | 2.1 | .40 | .30 | 11,000 | 8,300 | 7 | 3 | 2.9 | 2.7 |
| 4.0 | About 15.2 km below RWTP at 1st Ave. S. Bridge (Hwy. 509) | .62 | .05 | 1.5 | .008 | --- | .40 | .30 | --- | --- | -- | -- | --- | --- |

3/ Ortho-phosphates in some cases exceeded total phosphates due to unknown factors.

Table 4. Summary of total chlorine (residual) sampling data collected from the Green/Duwamish River during November 8 and 15, 1979.

| Station | November 7 Sampling Run (Start Drift at Mid-Flood Tide) | | November 15 Sampling Run (Start Drift at High Slack Tide) | |
|---|---|---|---|---|
| | Distance Below Renton STP (meters) | Total Chlorine (Residual) (mg/1) | Distance Below Renton STP (meters) | Total Chlorine (Residual) (mg/1) |
| 1. | 0 | .08 | 0 | .20 |
| 2. | 100 | .07 | 0 | .16 |
| 3. | 500 | .05 | 100 | .13 |
| 4. | 550 | .06 | 250 | .12 |
| 5. | 1,050 | .03 | 350[1/] | .15 |
| 6. | 1,300 | .04 | 500 | .18 |
| 7. | 1,500 | .03 | 550 | .15 |
| 8. | 1,800 | .03 | 600 | .08 |
| 9. | 2,200 | .01 | 1,000 | .07 |
| 10. | 2,400 | .01 | 1,300 | .06 |
| 11. | 2,700 | .01 | 1,200 | .03 |
| 12. | 2,900 | .01 | 1,600 | .07 |
| 13. | 3,200 | .01 | 1,300[1/] | .03 |
| 14. | | | 2,100 | .04 |

[1/]Periodically moved drogues a short distance upstream in an attempt to delineate dimensions of the poor-dilution block.

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## APPENDIX A

1. State of Washington, Department of Ecology Effluent Dilution Zone Guidelines.

2. State of Washington, Department of Ecology Water Quality Standards; WAC 173-201-050, Characteristic Uses to be Protected.

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Chapter 25
EFFLUENT DILUTION ZONE GUIDELINES

25.1 Regulations [Revised 3/80]

The State of Washington water quality regulations directly relating to the establishment of dilution zones are:

"The total area and/or volume of a receiving water assigned to a dilution zone shall be as described in a valid discharge permit as needed and be limited to that which will:

a. Not cause acute mortalities of sport, food, or commercial fish and shellfish species of established biological communities within populations or important species to a degree which damages the ecosystem.

b. Not diminish aesthetic values or other beneficial uses disproportionately."

25.2 General Requirements for Dilution Zones

The quality of water outside the dilution zone shall be maintained at the existing water quality or shall satisfy established water quality standards, whichever requirement is higher.

Dilution zones shall be located in an area of the receiving water where the effluent will have no effect on beneficial uses. These uses include migration of aquatic life, recreational uses, and agricultural uses.

The overlapping and interference of two or more dilution zones are not permitted. No dilution zone will be permitted for new developments or facilities when the dilution ratio of receiving water to effluent is less than 20:1.*

No dilution zones will be permitted in lakes with a surface area of less than 1,000 acres. For lakes with surface areas greater than 1,000 acres, a dilution zone will be permitted if advanced waste treatment is provided to the effluent. The dilution zone location for lakes shall be handled on a case-by-case basis to the satisfaction of the Department.

No exposed discharges will be permitted.

No dilution zones for new sources will be allowed in areas where existing water quality does not meet established receiving water quality criteria.

---

* A 10-year, 7-day low flow or a low flow established by regulation shall be used in the calculations.

Source: Department of Ecology, 1978. "Criteria for Sewage Works Design".

25.3 Rivers [Revised 3/80]

Dilution zone boundaries shall not encompass more than 15 percent of the width of a stream or include more than 15 percent of the volume of the river flow.* For rivers less than 680 feet wide, the dilution zone boundary with respect to the waterline at low flow* shall begin at a point from the shore that is a minimum of 15 percent of the stream width. For rivers greater than 680 feet in width, the dilution zone boundary shall be a minimum of 100 feet out from the waterline at low flow.*

The following is the dilution zone depth, width, and length description.

The upper limit of the dilution zone shall be one foot below the surface of the water (figure 7). The length of the dilution zone shall extend laterally to 300 feet from the centerline of the diffuser (figure 8).

The width of the dilution zone shall not extend into the shoreline areas described above (see figure 8) and will be either:

(a) The length of the diffuser plus 100 feet or

(b) 15 percent of the width of the stream; whichever is less.

25.4 Estuaries

The diffuser section of the outfall shall be situated to take advantage of predominant currents of the estuary. The dilution boundary shall be at least 100 feet from the shoreline measured at mean lower low water (figure 9).

The dilution zone depth, width, and length shall be as follows:

- The limits of the dilution zone in depth shall be one foot below the surface to one foot above the bottom (figure 10).
- The length of the dilution zone with respect to the centerline of the diffuser shall be 150 feet plus the depth of the water above the diffuser* (figure 11).
- The width of the dilution zone shall be the legth of the diffuser plus 100 feet plus the depth of the water above the diffuser or 15 percent of the width of the estuary, whichever is less (figure 11).

* A 10-year, 7-day low flow or a low flow established by regulation shall be used in the calculations.

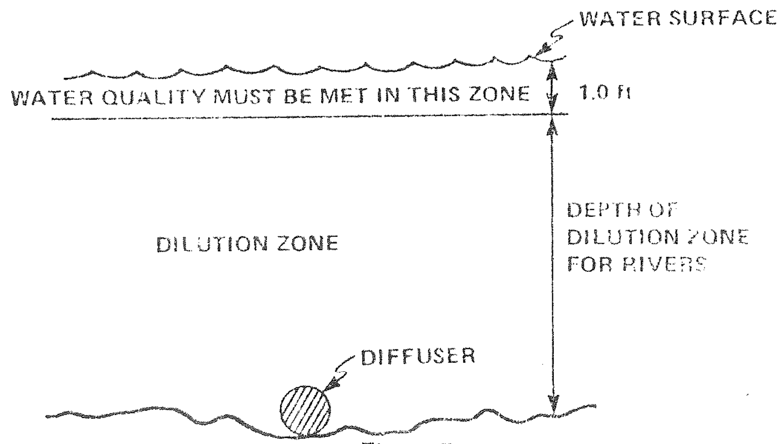


Figure 7
VERTICAL BOUNDARY OF RIVER DILUTION ZONE

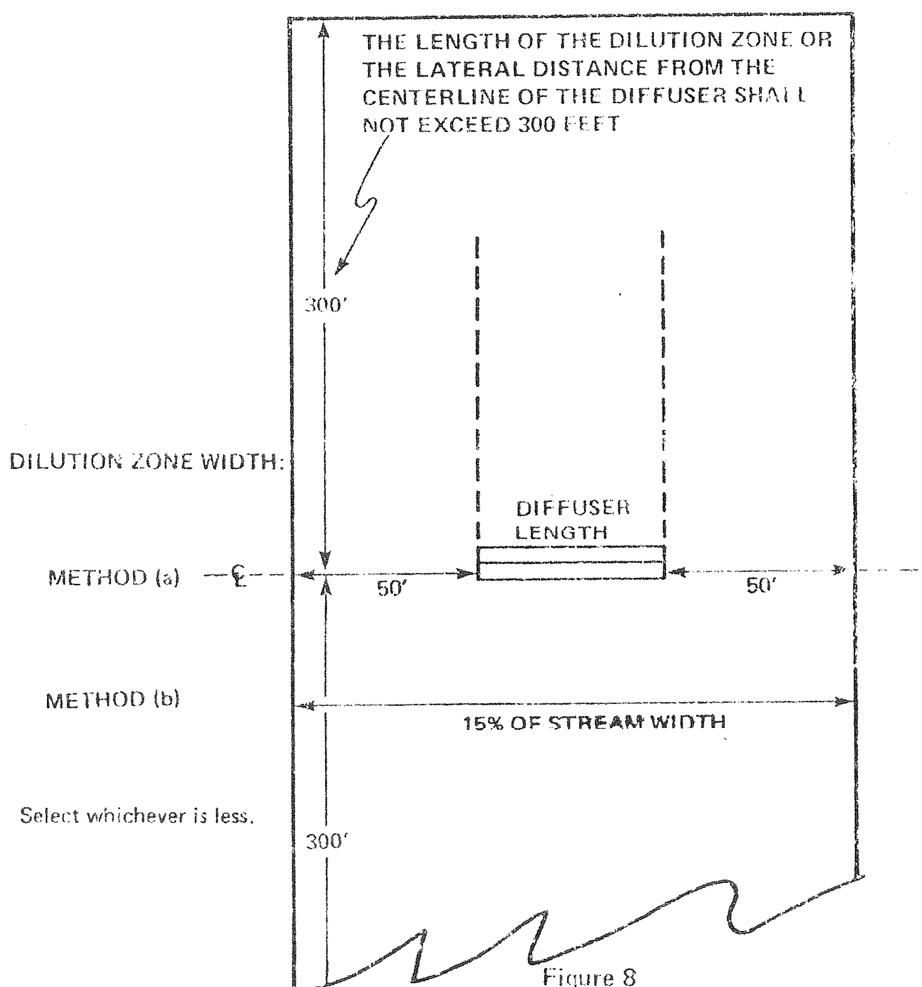


Figure 8
LENGTH AND WIDTH OF
RIVER DILUTION ZONE

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(2) CLASS A (EXCELLENT).

(a) General Characteristic. Water quality of this class shall meet or exceed the requirements for all or substantially all uses.

(b) Characteristic Uses. Characteristic uses shall include, but are not limited to, the following:

(i) Water supply (domestic, industrial, agricultural).

(ii) Wildlife habitat, stock watering.

(iii) General recreation and aesthetic enjoyment (picnicking, hiking, fishing, swimming, skiing, and boating).

(iv) Commerce and navigation.

(v) Fish and shellfish reproduction, rearing, and harvesting.

(c) Water Quality Criteria.

(i) Fecal Coliform Organisms

(A) Freshwater - Fecal Coliform Organisms shall not exceed a median value of 100 organisms/100 ml, with not more than 10 percent of samples exceeding 200 organisms/100 ml.

(B) Marine water - Fecal Coliform Organisms shall not exceed a median value of 14 organisms/100 ml, with not more than 10 percent of samples exceeding 43 organisms/100 ml.

(ii) Dissolved Oxygen.

(A) Freshwater - Dissolved oxygen shall exceed 8.0 mg/l.

(B) Marine water - Dissolved oxygen shall exceed 6.0 mg/l, except when the natural phenomenon of upwelling occurs, natural dissolved oxygen levels can be degraded by up to 0.2 mg/l by man-caused activities.

(iii) Total Dissolved Gas - the concentration of total dissolved gas shall not exceed 110 percent of saturation at any point of sample collection.

Source: Department of Ecology, 1977. "Washington State Water Quality Standards".

(iv) Temperature - water temperatures shall not exceed 18.0° Celsius (freshwater) or 16.0° Celsius (marine water) due to human activities. Temperature increases shall not, at any time, exceed $t = 28/(T + 7)$ (freshwater) or $t = 12/(T - 2)$ (marine water).

When natural conditions exceed 18.0° Celsius (freshwater) and 16.0° Celsius (marine water), no temperature increase will be allowed which will raise the receiving water temperature by greater than 0.3° Celsius.

For purposes hereof, "t" represents the permissive temperature change across the dilution zone; and "T" represents the highest existing temperature in this water classification outside of any dilution zone.

Provided that temperature increase resulting from nonpoint source activities shall not exceed 2.8° Celsius, and the maximum water temperature shall not exceed 18.3° Celsius (freshwater).

(v) pH shall be within the range of 6.5 to 8.5 (freshwater) or 7.0 to 8.5 (marine water) with a man-caused variation within a range of less than 0.5 units.

(vi) Turbidity shall not exceed 5 NTU over background turbidity when the background turbidity is 50 NTU or less, or have more than a 10 percent increase in turbidity when the background turbidity is more than 50 NTU.

(vii) Toxic, radioactive, or deleterious material concentrations shall be below those of public health significance, or which may cause acute or chronic toxic conditions to the aquatic biota, or which may adversely affect any water use.

(viii) Aesthetic values shall not be impaired by the presence of materials or their effects, excluding those of natural origin, which offend the senses of sight, smell, touch, or taste.

(3) CLASS B (GOOD).

(a) General Characteristic. Water quality of this class shall meet or exceed the requirements for most uses.

(b) Characteristic Uses. Characteristic uses shall include, but are not limited to, the following:

(i) Industrial and agricultural water supply.

(ii) Fishery and wildlife habitat.

(iii) General recreation and aesthetic enjoyment (picnicking, hiking, fishing, and boating).

(iv) Stock watering.

(v) Commerce and navigation.

(vi) Shellfish reproduction and rearing, and crustacea (crabs, shrimp, etc.) harvesting.

(c) Water Quality Criteria.

(i) Fecal Coliform Organisms.

(A) Freshwater - Fecal Coliform Organisms shall not exceed a median value of 200 organisms/100 ml, with not more than 10 percent of samples exceeding 400 organisms/100 ml.

(B) Marine water - Fecal Coliform Organisms shall not exceed a median value of 100 organisms/100 ml, with not more than 10 percent of samples exceeding 200 organisms/100 ml.

(ii) Dissolved Oxygen.

(A) Freshwater - Dissolved oxygen shall exceed 6.5 mg/l or 70 percent saturation whichever is greater.

(B) Marine water - Dissolved oxygen shall exceed 5.0 mg/l or 70 percent saturation, whichever is greater, except when the natural phenomenon of upwelling occurs, natural dissolved oxygen levels can be degraded by up to 0.2 mg/l by man-caused activities.

(iii) Total Dissolved Gas - the concentration of total dissolved gas shall not exceed 110 percent of saturation at any point of sample collection.

(iv) Temperature - water temperatures shall not exceed 21.0° Celsius (freshwater) or 19.0° Celsius (marine water) due to human activities. Temperature increases shall not, at any time, exceed $t = 34/(T+9)$ (freshwater) or $t = 16/T$ (marine water).

When natural conditions exceed 21.0° Celsius (freshwater) and 19.0° Celsius (marine water), no temperature increase will be allowed which will raise the receiving water temperature by greater than 0.3° Celsius.

For purposes hereof, "t" represents the permissive temperature change across the dilution zone; and "T" represents the highest existing temperature in this water classification outside of any dilution zone.

Provided that temperature increase resulting from nonpoint source activities shall not exceed 2.8° Celsius, and the maximum water temperature shall not exceed 21.3° Celsius (freshwater).

(v) pH shall be within the range of 6.5 to 8.5 (freshwater) and 7.0 to 8.5 (marine water) with a man-caused variation within a range of less than 0.5 units.

(vi) Turbidity shall not exceed 10 NTU over background turbidity when the background turbidity is 50 NTU or less, or have more than a 20 percent increase in turbidity when the background turbidity is more than 50 NTU.

(vii) Toxic, radioactive, or deleterious material concentrations shall be below those which adversely affect public health during characteristic uses, or which may cause acute or chronic toxic conditions to the aquatic biota, or which may adversely affect characteristic water uses.

(viii) Aesthetic values shall not be reduced by dissolved, suspended, floating, or submerged matter not attributed to natural causes, so as to affect water use or taint the flesh of edible species.

(4) CLASS C (FAIR).

(a) General Characteristic. Water quality of this class shall meet or exceed the requirements of selected and essential uses.

(b) Characteristic Uses. Characteristic uses shall include, but are not limited to, the following:

Part II

# THE IMPACT OF EFFLUENT FROM THE RENTON WASTEWATER TREATMENT PLANT ON THE DISSOLVED OXYGEN REGIMEN OF THE LOWER GREEN/DUWAMISH RIVER

by

William E. Yake

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ABSTRACT

The impact of Renton wastewater treatment plant effluent on dissolved oxygen concentrations in the lower Green/Duwamish River was modelled using a modification of the Streeter-Phelps equation which accounts for longitudinal dispersion. Rate constants and other variables were determined from data collected during two 24-hour drift surveys conducted during September and October of 1979.

Dissolved oxygen concentrations below the plant discharge were depressed 2 to 3 mg/l. Based on model results and interpretation of survey data, nitrification of effluent ammonia was found to be responsible for about 95 percent of the observed dissolved oxygen depression. Model extrapolation to 1985 suggests further substantial degradation of the lower Green/Duwamish River as plant flow increases and instream dilution ratios decrease.

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THE IMPACT OF EFFLUENT FROM THE RENTON WASTEWATER TREATMENT PLANT ON THE DISSOLVED OXYGEN REGIMEN OF THE LOWER GREEN/DUWAMISH RIVER

## Introduction

During September, October, and November of 1979, the Water and Wastewater Monitoring Section of the Department of Ecology (DOE) conducted a series of studies to define the impact of the Renton wastewater treatment plant effluent on the lower Green River and Duwamish Waterway during low river flow conditions. Hydraulic, organic, and solids loading to the plant have continued to increase substantially during the past several years and concern has grown that the assimilative capacity of the Green River is being approached or exceeded. During low river flows, dilution ratios have dropped to as low as 4:1 (river flow: effluent flow).

This paper focuses on the effect of the Renton effluent on dissolved oxygen concentrations in the freshwater portion of the lower Green River. The dissolved oxygen regimen of the lower Green River is modelled and the effects of in-stream nitrification of effluent ammonia receive special attention.

Certain parameters incorporated into the model are expressed in common English units. For this reason, the text and graphics of this report use the same units. To aid in the conversion of common English units to metric units, the following table is provided:

Table 1. Conversion Table, English to Metric Units.

| English Unit | Conversion Factor | | Metric Unit |
|---|---|---|---|
| Feet (ft) | x 0.3048 | = | meters (m) |
| Miles (M) | x 1.609 | = | Kilometers (km) |
| Feet/second (fps) | x 18.288 | = | Meters/min. |
| Miles/hr. (mph) | x 1.609 | = | Kilometers/hr. (kph) |
| Pounds (lbs) | x 0.4536 | = | Kilograms (kg) |
| Million gallons/day (MGD) | x 2.6288 | = | Cubic meters/min. |
| Cubic feet/second (cfs) | x 28.315 | = | Liters/second |
| | x 101.93 | = | Cubic meters/hr. |

## Setting

The studies conducted on the Green/Duwamish system focused on the tidally influenced portion from the mouth at Elliott Bay to River Mile (R.M.) 13 (see Figure 1). The Renton plant discharges at R.M. 12 and,

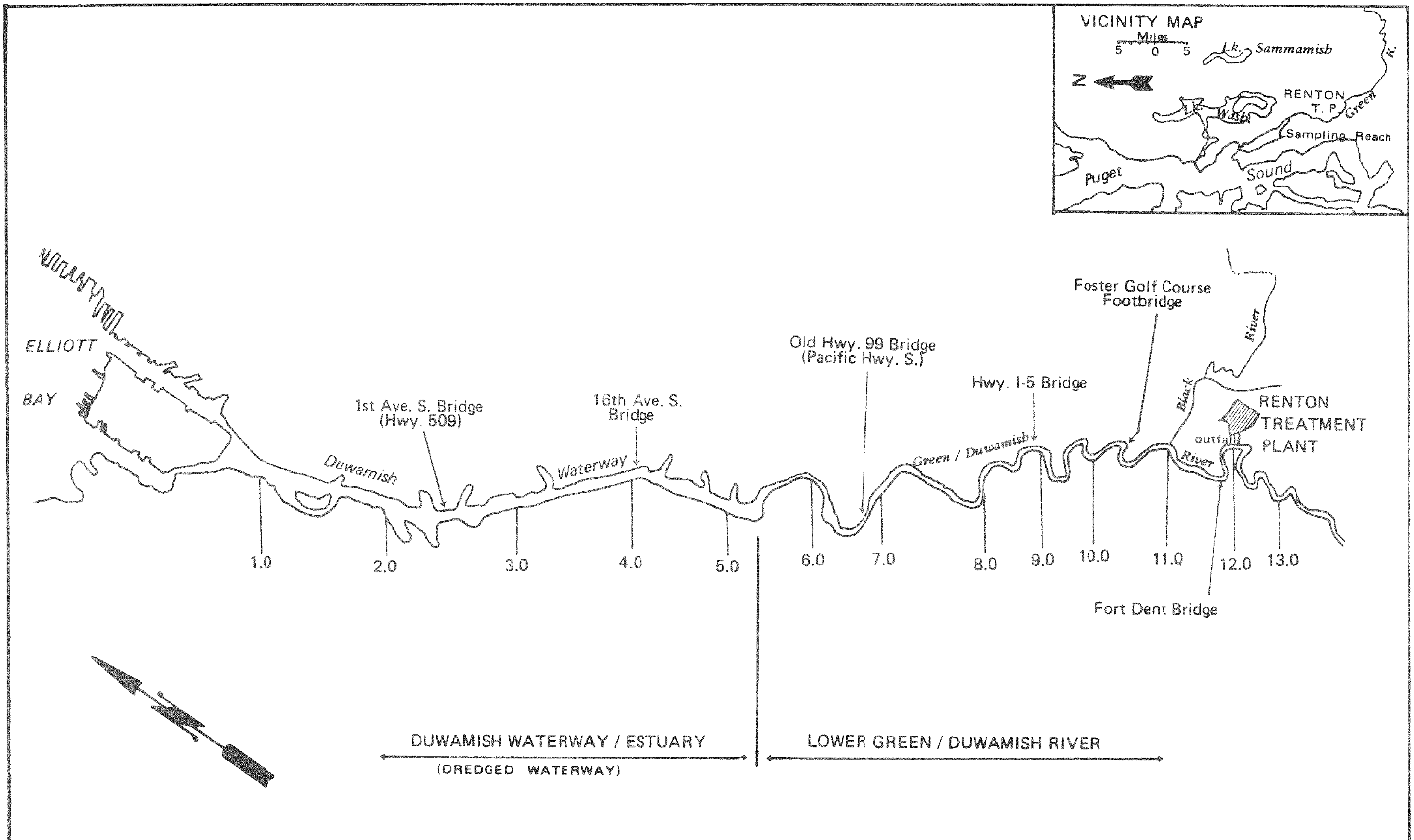



Figure 1. DUWAMISH RIVER INTENSIVE STUDY AREA WITH RIVER MILE INDEX

Original:
Duwamish River Intensive
Survey Memorandum
by John Bernhardt
Dec. 19, 1979

although tidally influenced, the river remains predominantly fresh until R.M. 7. The portion between R.M. 7 and R.M. 5 can range from 0-40% saltwater depending on tide stage and river flow. Low dissolved oxygen concentrations in the saltwater estuarine portion of the system have been noted previously (Pyrch, et al., 1976). Depressed oxygen concentrations in the lower estuary have historically been attributed to the low oxygen concentrations in a saltwater wedge. This wedge-water moves upstream slowly and is continually stripped into the fresher surface waters, by the net seaward movement of the river. The rate of stripping (and thus the age and dissolved oxygen concentration) of this wedge-water is controlled largely by river flow. Surface concentrations of dissolved oxygen are a function of dissolved oxygen concentrations in the wedge, amount of saltwater present in surface waters, and reaeration rates in the estuary. Worst-case conditions exist, therefore, during the later summer and fall when river flows are lowest and dissolved oxygen concentrations at depth (i.e., in the wedge) are lowest.

Tidal action also significantly affects the distribution of effluent in the river. Because even moderate high tides reverse river flow at the effluent outfall, that portion of the river from immediately above the outfall to several miles below the outfall is subjected to slugs of poorly diluted effluent, usually twice a day. These "poor dilution blocks" were observed to contain up to 60% effluent. As the blocks move downstream, they disperse longitudinally and appear to lose their integrity after one complete tidal exchange.

The river portion of the system (R.M. 6 to 13) has a bed consisting of silt and sand with riprap along much of the bank side. Average river depth is here assumed to be 5 feet, although detailed soundings were not conducted.

The Renton wastewater treatment plant is an activated sludge plant with a present average daily dry weather flow of about 36 MGD. According to the plant's operations supervisor (Finger, personal communication), flow from approximately noon to 2:00 a.m. is about 50% greater than the average flow. It is estimated that dry weather flows at the plant are increasing at the rate of about 1.7 MGD per year (Nunnallee, personal communication).

Based on design criteria, the plant is approximately 45% organically overloaded (Nunnallee, 1979). Under these adverse conditions, only tight operational control allows the plant to consistently meet its permit limitations of 15 mg/l for carbonaceous BOD and suspended solids. Because waste activated sludge is exported to the West Point treatment plant for treatment and disposal, the Renton plant has greater latitude in the quantity and type of sludge generated than would an ordinary activated sludge plant with on-site sludge digestion. During the study period, the plant was operating with a very low sludge age (1 to 2 days). One reason for this mode of operation is to explicitly avoid nitrification. Aeration capability at the plant is limited and full nitrification would be difficult without additional aeration capacity.

During the study there was no evidence of in-plant nitrification; all inorganic nitrogen was discharged to the Green/Duwamish system as ammonia.

## Methods

Most of the data upon which this paper is based were collected during two 24-hour time-of-travel surveys. Drogues were placed at the outfall and tracked for 24 hours. The first survey (9/18-19/79) was begun about an hour before the full effects of high tide were evidenced at the outfall. During high tide, as previously noted, a poor dilution block forms with concentrations of up to 60% effluent. This drift began in that block. The second survey (10/2-3/79) was begun during low tide. Under these conditions, the dilution of effluent is rapid. Water samples were collected and field analyses were performed at frequent (15-minute) intervals at the beginning of each drift. Sampling intervals decreased to once every three hours by the end of the survey. The time and location of each sampling site was recorded. Water quality analyses which are incorporated into this paper include temperature, dissolved oxygen, specific conductivity, nitrate-N, nitrite-N, and ammonia-N. Field tests and laboratory analyses of effluent samples obtained immediately prior to each drift defined effluent characteristics including multiple day carbonaceous BOD, specific conductivity, temperature, nitrate-N, nitrite-N, and ammonia-N. Effluent flow at the beginning of each drift was obtained from the treatment plant's effluent flow meter and river flow was calculated from velocity and depth measurements obtained at 2-foot cross-stream intervals using a magnetic flow meter with top-setting rod.

## Model Formulation

After reviewing the data obtained during this survey, several phenomena were apparent. Dissolved oxygen concentrations were depressed downstream from the outfall and the concentrations of nitrate and nitrite increased with time as the drift progressed. The data were somewhat difficult to interpret, as tidal effects resulted in receiving water samples with varying effluent concentrations. To clarify these results and better define the causes of the dissolved oxygen depression, the freshwater portion of the system was modelled. This model was based on a model developed by John Yearsley of USEPA Region X (Yearsley, 1976, 1978). Substantial changes were made in the model. Therefore, descriptions of the major model elements and assumptions are included here.

The central equation of the model is given in Equation 1 (O'Connor and Thomann, 1971).

Eq. 1 $$D_x = D_o - \left(\frac{K_1}{K_2-K_1}\right) \frac{e^{F(1-\sqrt{A_1})x}}{A_1} - \frac{e^{F(1-\sqrt{A_2})x}}{A_2} \quad C_c +$$

$$\left(\frac{K_3}{K_2-K_3}\right) \frac{e^{F(1-\sqrt{A_3})x}}{A_3} - \frac{e^{F(1-\sqrt{A_2})x}}{A_2} \quad C_n + (D_s-D_o)\left(\frac{e^{F(1-\sqrt{A_2})x}}{A_2}\right)$$

where $F = u/2\varepsilon$

$A_1 = 1 + 4K_1\varepsilon/u^2$

$A_2 = 1 + 4K_2\varepsilon/u^2$

$A_3 = 1 + 4K_3\varepsilon/u^2$

$D_x$ = dissolved oxygen concentration at a location x ft. downstream from effluent discharge

$D_o$ = dissolved oxygen concentration after initial mixing (x = o), mg/l

$D_s$ = saturation oxygen concentration, mg/l

and, $K_1$ = carbonaceous BOD rate constant, base e, $sec^{-1}$

$K_2$ = reaeration rate constant, base e, $sec^{-1}$

$K_3$ = nitrification rate constant, base e, $sec^{-1}$

u = net mean downstream velocity, ft/sec

$\varepsilon$ = dispersion coefficient, $ft^2/sec$

$C_c$ = ultimate carbonaceous BOD concentration after initial mixing mg/l

$C_n$ = nitrogenous oxygen demand concentration after initial mixing mg/l

x = distance downstream from discharge, ft

$F = {}^{u}/_{2\varepsilon}$

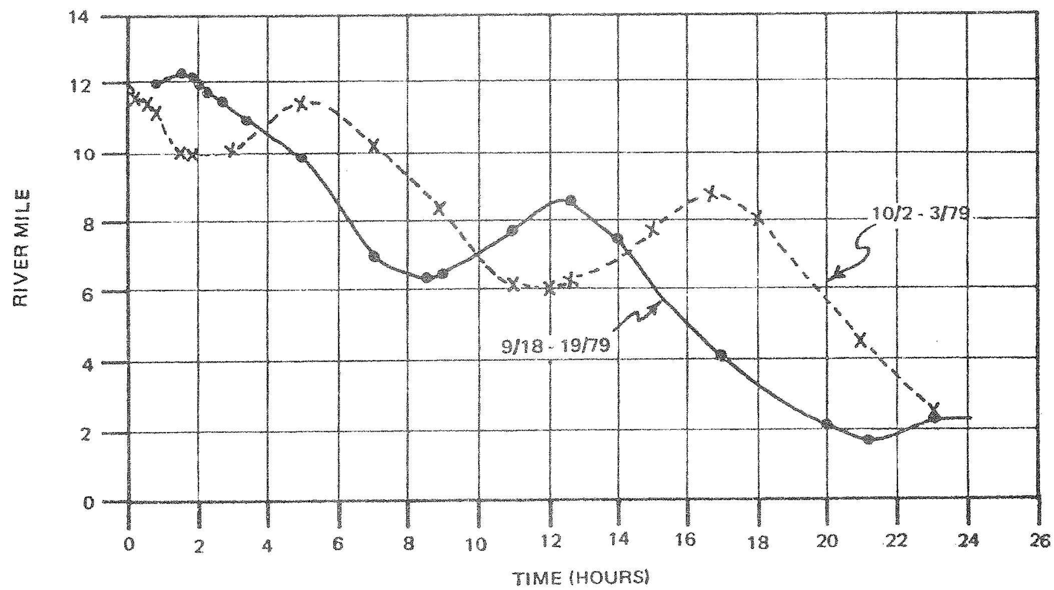
This equation is an adaptation of the classic Streeter-Phelps oxygen sag equation which accounts for the longitudinal dispersion present in tidally influenced systems. The dispersion coefficient ($\varepsilon$) used here is 80 $ft^2/sec$, the average value obtained by Fischer (1978).

Determination of values used in the model will be discussed in some detail.

## Velocity (u)

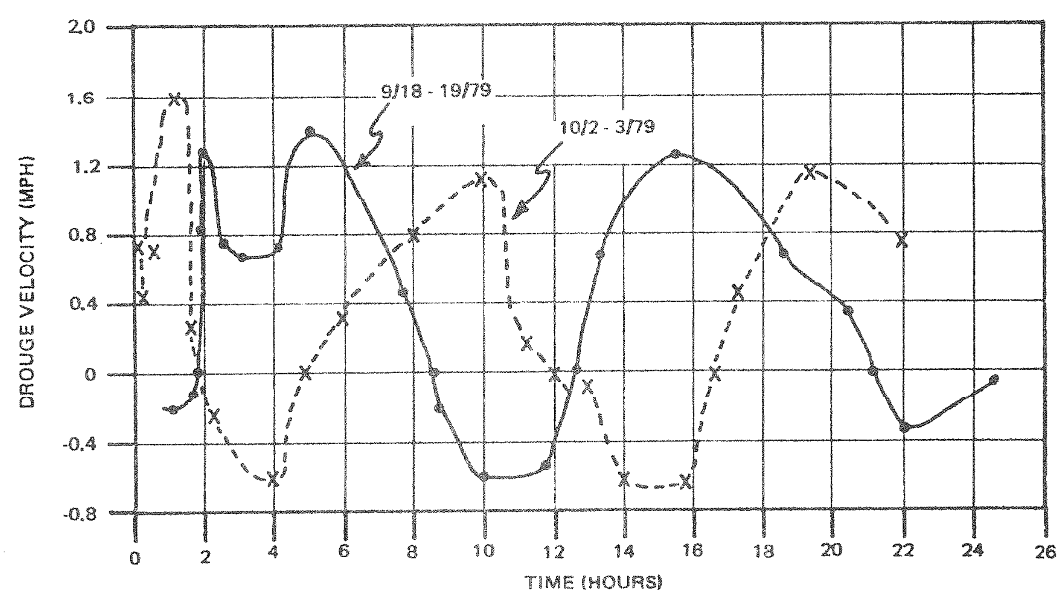
Velocity measurements are based on drogue locations and times recorded during each drift. Figures 2 and 3 present these location and velocity data. The model is valid only for the freshwater portion of the system (R.M. 12 to approximately R.M. 6). The

FIGURE 2




DROGUE LOCATION CURVES

FIGURE 3




DROGUE VELOCITY CURVES

difficulty posed in determining an average velocity is apparent in Figure 2. For instance, on the 9/18-19/79 drift, river mile 6 was approached at 8.5 hours and 15.2 hours, providing two substantially different net downstream velocities for this portion of the system. For this portion of the system, a range of net drogue velocities was calculated. Velocities were then adjusted by assuming that "water velocity" was equal to 0.85 times "drogue velocity" to account for the higher average velocity at the surface of the river. The results of these calculations are given in Table 2.

Table 2. Calculated Velocities

A. Over Full Length of Drift (R.M. 12 to 2)

| | 9/18-19/79 | | 10/2-3/79 | |
|---|---|---|---|---|
| | mph | ft/sec | mph | ft/sec |
| Net Drogue Velocity | 0.40 | 0.59 | 0.41 | 0.60 |
| Net Water Velocity | 0.35 | 0.51 | 0.35 | 0.51 |

B. Freshwater Portion Only (R.M. 12 to 6)

| | 9/18-19/79 | | 10/2-3/79 | |
|---|---|---|---|---|
| | mph | ft/sec | mph | ft/sec |
| Net Drogue Velocity | 0.39-0.73 | 0.91-1.07 | 0.32-0.49 | 0.46-0.67 |
| Net Water Velocity | 0.34-0.64 | 0.51-0.95 | 0.28-0.40 | 0.41-0.59 |

As a best approximation, the following velocities were used in the model:

| Date | Net Water Velocity |
|---|---|
| 9/18-19/79 | 0.73 ft/sec |
| 10/2-3/79 | 0.50 ft/sec |

Saturation Concentration of Dissolved Oxygen ($D_s$)

Equation 2 is used to give the saturation concentration of dissolved oxygen.

Eq. 2 $$D_s = (14.6214 - .3898\ T + .006969\ T^2 - .0005897\ T^3)\ P$$

where: $P$ = the partial pressure of oxygen = $(P_1 - P_2)/(760 - P_2)$

$P_1$ = atmospheric pressure (mm Hg)

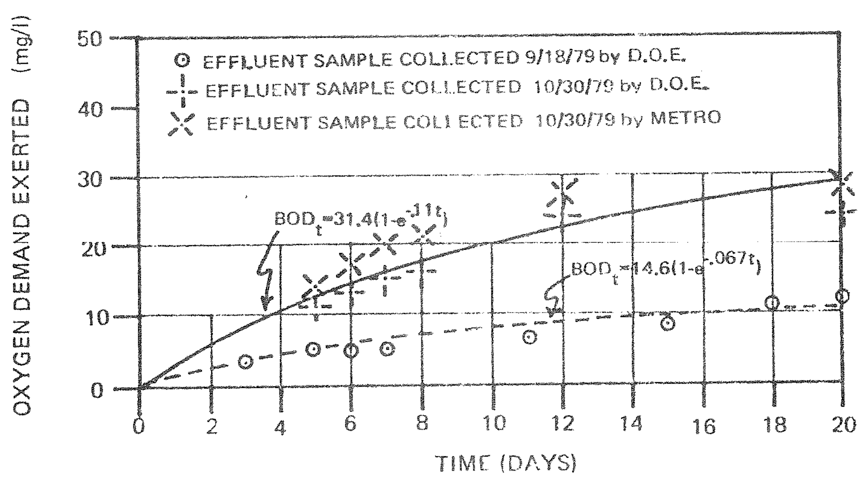
$P_2 = 4.879\ (\exp(.06378\ T))$

$T$ = temperature (°C)

## Carbonaceous Biochemical Oxygen Demand ($C_c$) and Rate Constant ($K_1$)

Effluent carbonaceous $BOD_5$ concentrations were determined by analyses of samples taken at the beginning of each drift. Long-term, multiple-day carbonaceous BOD tests were conducted on the effluent sample collected on 9/18/79 and on composite effluent samples collected on 10/30-31/79 by both DOE and Renton treatment plant personnel. Nitrification was inhibited in all tests with Hach Nitrification Inhibitor Formula 2553™ (assumed to be 2-chlor, 6-trichlora, methylperidine). The results of these tests are shown in Figure 4.

FIGURE 4.




CARBONACEOUS OXIDATION CURVES

Standard first-order curves were fitted to the data. The resultant carbonaceous BOD rate constants are given below.

| Date | $K_1$(20°C, base e) |
|---|---|
| 9/18-19/79 | .067 $day^{-1}$ |
| 10/30-31/79 | .11 $day^{-1}$ |

The average value of .09 $day^{-1}$ was used in the model. This is a rate which is typical of secondary sewage effluents. Temperature effects on $K_1$ are accounted for by using the standard temperature correction equation:

Eq. 3 $$K_{1,T} = K_{1,20} (1.045^{(T-20)})$$

where: T = water temperature (°C)

The initial concentration of ultimate BOD ($C_c$) in the river is determined by summing the $BOD_5$ loadings from the river and plant, and dividing this sum by downstream river flow. This output is downstream concentration of $BOD_5$ in mg/l. This is converted to ultimate BOD concentration using equation 4.

$$\text{Eq. 4} \qquad C_c = \frac{C_{c,5}}{(1- e^{5K_{1,20}})}$$

<u>Nitrogenous Oxygen Demand ($C_n$) and Rate Constant ($K_3$)</u>

The rate ($K_3$) at which ammonium ($NH_4^+$) is oxidized to nitrite ($NO_2^-$) and, ultimately, nitrate ($NO_3^-$) is highly dependent on environmental conditions. Unlike carbonaceous BOD, which is generally oxidized by a spectrum of heterotrophic bacteria in the water column, ammonia is oxidized by a few specialized genera of bacteria. These nitrifers are typically found attached to substrate. Therefore, the nitrification rate is a function of river bottom area:water volume ratios, as well as substrate type. The rate is also highly temperature and pH sensitive. For these reasons, although the nitrification rate constant has been estimated from laboratory tests (Harper, 1976; Welch, 1980), we chose to estimate $K_3$ from in-stream data.

As noted previously, the formation of poor dilution blocks during high tide, the variable treatment plant flow rate, and longitudinal tidal mixing made interpretation of raw data difficult. For this reason, raw in-stream data were converted to a standard base. First, the decimal fraction of effluent in the sample was determined using equation 5.

$$\text{Eq. 5} \qquad f_e = \frac{C_s - C_u}{C_e - C_u}$$

where: $f_e$ = the decimal fraction effluent in the sample

$C_s$ = the concentration of a conservative tracer in the sample

$C_u$ = the concentration of the tracer upstream of the discharge

$C_e$ = the concentration of the tracer in the effluent

For this calculation, measures of specific conductivity (μmhos/cm) were used to determine the decimal fraction. This measure proved useful on most samples. Some of the lower river samples (R.M. 6-7) had somewhat elevated conductivities, probably due to fractional (about 5%) contamination by saltwater. In these cases, a fully mixed condition was assumed and the decimal fraction was based on the initial plant and river flow rates.

Using this decimal fraction, the "expected concentration" (i.e., assuming no nitrification or alteration of nitrogen forms) of various parameters including $NO_2^-$, $NO_3^-$ and $O_2$ was determined using equation 6.

Eq. 6 $$C = f_e(C_e) + f_r(C_r)$$

where:
- $C$ = expected concentration (mg/l)
- $f_e$ = decimal fraction of effluent in sample
- $C_e$ = concentration in effluent (mg/l)
- $f_r$ = $1-f_e$ = decimal fraction of upstream river water in sample
- $C_r$ = concentration in upstream river

Using this technique with total inorganic nitrogen ($NO_3$-N + $NO_2$-N + $NH_4$-N) and total nitrogen ($NO_3$-N + $NO_2$-N + $NH_4$-N + Organic N) it was apparent that inorganic and total nitrogen forms (taken in total) were conservative. That is, no sources or sinks were apparent between R.M. 12 and 6. The decision was made to use $NO_2^-$ and $NO_3^-$ generation rather than $NH_4^+$ consumption, to determine the nitrification rate constant. This decision was based on the observation that standard analytical imprecision on the higher ammonia concentrations would obscure the effects of nitrification, while the substantial increases in initially low levels of $NO_2^-$ and $NO_3^-$ would provide a more precise measure.

Using equation 6, expected levels of $NO_2$-N and $NO_3$-N were calculated. These were then subtracted from "actual" measured concentrations to give generated concentrations (Table 3A,B). Because no $NO_2^-$ was initially detected in either effluent or river water, the oxygen required to produce the generated (excess) $NO_2^-$ and $NO_3^-$ could be determined using the stoichiometric oxygen requirements for the oxidation of $NH_4$-N to $NO_2$-N (3.35 g $O_2$ required/g $NO_2$-N generated) and $NO_3$-N (4.57 g $O_2$ required/g $NO_3$-N generated). The actual oxygen depletion in the sample was also calculated to serve as a rough measure of total oxygen demand minus reaeration. These values were then adjusted back to a common base (in this case, pure effluent) by dividing the resulting oxygen demands by the decimal fraction of effluent in the sample. These results are tabulated in Table 3. Note that for the data collected on 9/18-19/79, the total oxygen demand detected is consistently 20 to 80% higher than the nitrogenous oxygen demand (NOD). 10/2-3/79 data do not display this consistent difference. Because, as later modelling results will illustrate, carbonaceous BOD appears to account for less than 5% of the total oxygen deficit, this suggests the presence of an oxygen demand during the 9/18-19/79 survey which was not accounted for in the survey or subsequent modelling.

Table 3A. Calculations of In-stream Oxygen Demand and Nitrogenous Oxygen Demand (9/18-19/79)

| River Mile | Actual Elapsed Time | | Mean Velocity Time | | Calculated Fraction | Expected Concentrations (mg/l) without Oxygen Demand | | | Actual Concentrations (mg/l) | | | Actual Minus Expected Concentrations (mg/l) | | | Oxygen Demand Adjusted to 100% Effluent (mg/l) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Hrs. | Days | Hrs. | Days | Effluent | $O_2$ | $NO_2$-N | $NO_3$-N | $O_2$ | $NO_2$-N | $NO_3$-N | $O_2$ | $NO_2$-N | $NO_3$-N | OD[1] | NOD[2] |
| 11.9 | .25 | .010 | .20 | .008 | .58 | 7.66 | 0 | .13 | 7.4 | .01 | .14 | .26 | .01 | .01 | 0.45 | .137 |
| 11.5 | .70 | .029 | 1.00 | .042 | .50 | 7.90 | 0 | .155 | 7.5 | .02 | .17 | .40 | .02 | .015 | 0.80 | .271 |
| 11.0 | 1.45 | .060 | 2.00 | .083 | .36 | 8.32 | 0 | .198 | 7.6 | .03 | .27 | .72 | .03 | .072 | 2.00 | 1.19 |
| 9.9 | 2.95 | .123 | 4.20 | .175 | .20 | 8.80 | 0 | .26 | 7.7 | .04 | .48 | 1.1 | .04 | .12 | 5.50 | 3.41 |
| 7.1 | 4.95 | .206 | 9.80 | .408 | (.20) | 8.80 | 0 | .26 | 6.6 | .05 | .62 | 2.2 | .05 | .36 | 11.0 | 9.06 |
| 6.5 | 6.95 | .290 | 11.0 | .458 | (.20) | 8.80 | 0 | .26 | 6.3 | .05 | .67 | 2.5 | .05 | .41 | 12.5 | 10.2 |
| 7.7 | 8.95 | .373 | 8.6 | .358 | (.20) | 8.80 | 0 | .26 | 6.2 | .06 | .66 | 2.6 | .06 | .40 | 13.0 | 10.1 |
| 7.5 | 11.95 | .498 | 9.0 | .375 | (.20) | 8.80 | 0 | .26 | 6.1 | .06 | .60 | 2.7 | .06 | .34 | 13.5 | 8.78 |



Table 3B. Calculations of In-stream Oxygen Demand and Nitrogenous Oxygen Demand (10/2-3/79)

| River Mile | Actual Elapsed Time Hrs. | Actual Elapsed Time Days | Mean Velocity Time Hrs. | Mean Velocity Time Days | Calculated Fraction Effluent | Expected $O_2$ | Expected $NO_2$-N | Expected $NO_3$-N | Actual $O_2$ | Actual $NO_2$-N | Actual $NO_3$-N | Actual Minus Expected $O_2$ | Actual Minus Expected $NO_2$-N | Actual Minus Expected $NO_3$-N | OD[1] | NOD[2] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 11.8 | .25 | .010 | .59 | .025 | .246 | 9.2 | 0 | .253 | 9.2 | <.01 | .31 | 0 | 0 | .057 | 0 | 1.06 |
| 11.7 | .50 | .021 | .88 | .037 | .159 | 9.2 | 0 | .282 | 9.0 | <.01 | --- | .2 | 0 | ---- | 1.26 | ----- |
| 11.5 | .75 | .031 | 1.47 | .061 | .154 | 9.2 | 0 | .283 | 8.9 | <.01 | .30 | .3 | 0 | .017 | 1.95 | .50 |
| 10.3 | 1.5 | .063 | 4.99 | .208 | .165 | 9.2 | 0 | .280 | 8.7 | .02 | .47 | .5 | .02 | .190 | 3.03 | 5.67 |
| 10.4 | 3.0 | .125 | 4.69 | .195 | .165 | 9.2 | 0 | .280 | 8.3 | .03 | .43 | .9 | .03 | .150 | 5.46 | 4.76 |
| 11.6 | 5.0 | .208 | 1.17 | .049 | .194 | 9.2 | 0 | .270 | 8.9 | .03 | .37 | .3 | .03 | .100 | 1.55 | 2.87 |
| 10.2 | 7.0 | .292 | 5.28 | .220 | .203 | 9.2 | 0 | .267 | 8.7 | .03 | .46 | .5 | .03 | .193 | 2.46 | 4.84 |
| 8.6 | 9.0 | .375 | 9.97 | .415 | .186 | 9.2 | 0 | .273 | 7.6 | .05 | .59 | 1.6 | .05 | .317 | 8.60 | 8.69 |
| 6.3 | 12.0 | .500 | 16.72 | .697 | (.189) | 9.2 | 0 | .272 | 6.9 | .05 | .70 | 2.3 | .05 | .428 | 12.2 | 11.24 |
| 7.8 | 15.0 | .625 | 12.32 | .513 | (.189) | 9.2 | 0 | .272 | 6.9 | .05 | .65 | 2.3 | .05 | .378 | 12.2 | 10.03 |
| 8.1 | 18.0 | .750 | 11.44 | .477 | (.189) | 9.2 | 0 | .272 | 7.1 | .05 | .63 | 2.1 | .05 | .358 | 11.1 | 9.54 |

[1] OD = oxygen demand exerted

[2] NOD = nitrogenous oxygen demand exerted

(  ) = based on initial plant and river flow rates

Two measures of time (that is, the "age" of the effluent in any sample) were used in rate determination. The first was the actual elapsed time required for the drogue to travel from the discharge to the sampling point. The second method was to use "net mean velocity time"; that is, the distance between the sampling point and the discharge, divided by "net water velocity" (see velocity determination). The time/NOD data are plotted in Figures 5 and 6. The curves fitted to the data points were of the form:

Eq. 7 $$NOD_t = NOD_u(1 - e^{-K_3 t})$$

where: $NOD_t$ = nitrogenous oxygen demand exerted by time t

$NOD_u$ = 4.57 x (original effluent ammonia concentration) = ultimate oxygen demand

$K_3$ = nitrification rate constant ($day^{-1}$)

t = time (days)

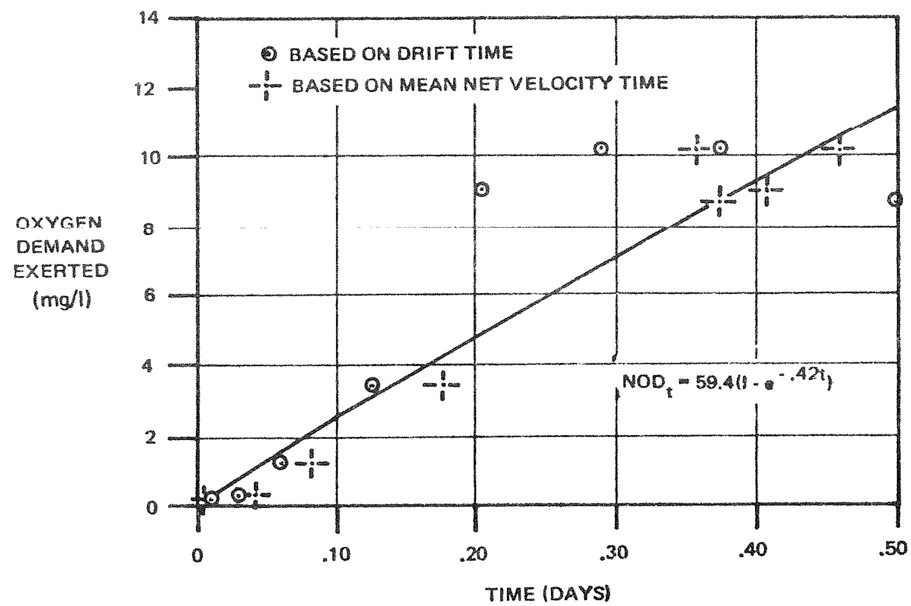
As can be noted in Figures 5 and 6, the "net mean velocity time" points generally fall closer to the line than the "actual elapsed time" points. Using net mean velocity time has two advantages: it accounts for the fact that water movement through the vertical profile is, on the average, moving about 15% slower than the surface drogues; and secondly, it provides some accounting for longitudinal mixing which disperses the original effluent parcel with "older" and "newer" effluent. The superiority of net mean velocity times in this determination suggests that longitudinal mixing procedes relatively rapidly.

The resulting rate constants and average water temperature were:

| Date | Average Temperature | $K_3$ (base e) |
|---|---|---|
| 9/18-19/79 | 18.0°C | .42 |
| 10/2-3/79 | 15.4°C | .30 |

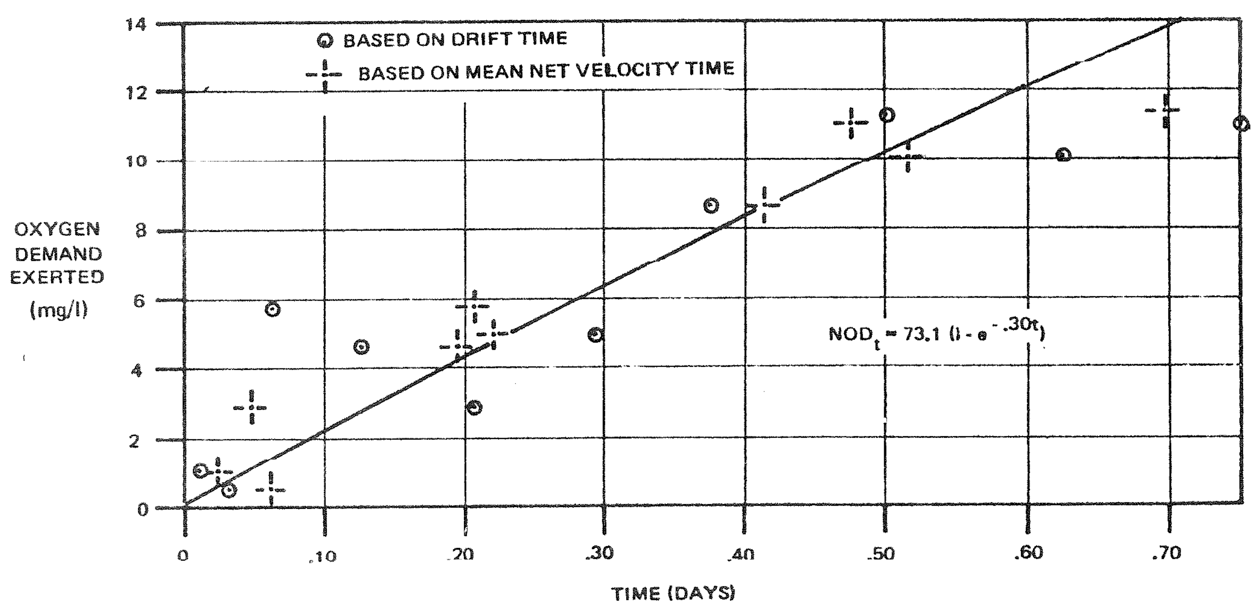
Although laboratory determinations of $K_3$ do not necessarily reflect environmental conditions in the receiving water, it is interesting to note that the rates determined here agree well with two independent laboratory determinations of the nitrification rate of Renton plant effluent. Harper (1976) reports rates between 0.17 and 0.60 $day^{-1}$ (20°C) determined for dechlorinated Renton effluent and Green River waters downstream of the discharge. The mean of the reported values was 0.34 $day^{-1}$. Welch and Trial (1979) has reported values of 0.28 to 0.45 $day^{-1}$ (20°C) for samples from three locations in Green River between the discharge and saltwater influence. The mean of these values was 0.39 $day^{-1}$. In a second

FIGURE 5




INSTREAM NITRIFICATION (9/18 - 19/79)

FIGURE 6




INSTREAM NITRIFICATION (10/2 - 3/79)

test with 1 mg $NH_4$-N/l added to these samples, Welch found rates of 0.20 to 0.38 $day^{-1}$ (20°C) with a mean of 0.31 $day^{-1}$.

As noted earlier, the nitrification rate is very sensitive to temperature variations. The temperature dependence of $K_3$ has been expressed by equation 8 (Fritz, et al., 1979):

Eq. 8a $$K_{3,T} = K_{3,15} \exp(.098\,(T-15))$$

where: $K_{3,T}$ = nitrification rate at temperature, T

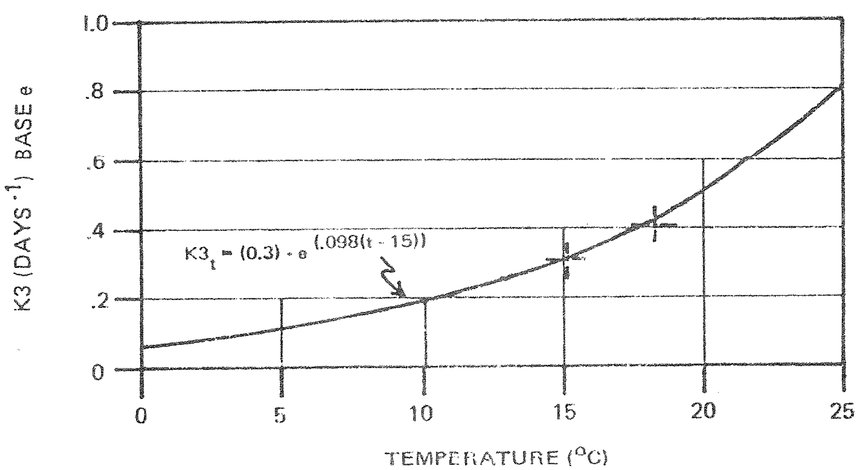
$K_{3,15}$ = nitrification rate at 15°C

$T$ = temperature (°C)

Using the rates and temperatures indicated above, the model uses the following equation for determining the nitrification rate at the prevailing water temperature (see figure 7).

Eq. 8b $$K_{3,T} = 0.30 \exp(.098(T-15))$$

FIGURE 7.




NITRIFICATION RATE CONSTANT AS FUNCTION OF TEMPERATURE

The initial concentration of ultimate NOD ($C_n$) in the river is determined by summing $NH_3$-N loading from the plant and the upstream river, multiplying this loading by 4.57 g $O_2$ required/g $NH_3$-N oxidized to $NO_3$-N, then dividing by total downstream flow. The output is downstream $NOD_u$ in mg/l.

Reaeration Rate ($K_2$)

Among the major variables, only the reaeration rate was not measured. An on-site measurement of reaeration rate would be a valuable contribution and should be considered in any future studies seeking to define de-oxygenation processes in the lower Green/Duwamish. Many equations are available for calculating reaeration based on river velocity, slope, depth, etc. The method chosen here was developed from Veltz's (1970) work by Hirsch (1980):

Eq. 9
$$K_2 = \frac{-\ln 1-2\,\dfrac{(1.42)(^{m}/60)(1.1^{(T-20)})}{\pi\,(30.48\ D)^2}^{.5}}{m/1440}$$

where: $m = 10.6\ (\ln D) - 6.05$ = mix interval (minutes)

and, $K_2$ = reaeration rate ($\text{days}^{-1}$)

$D$ = average river/estuary depth (ft)

$T$ = temperature (°C)

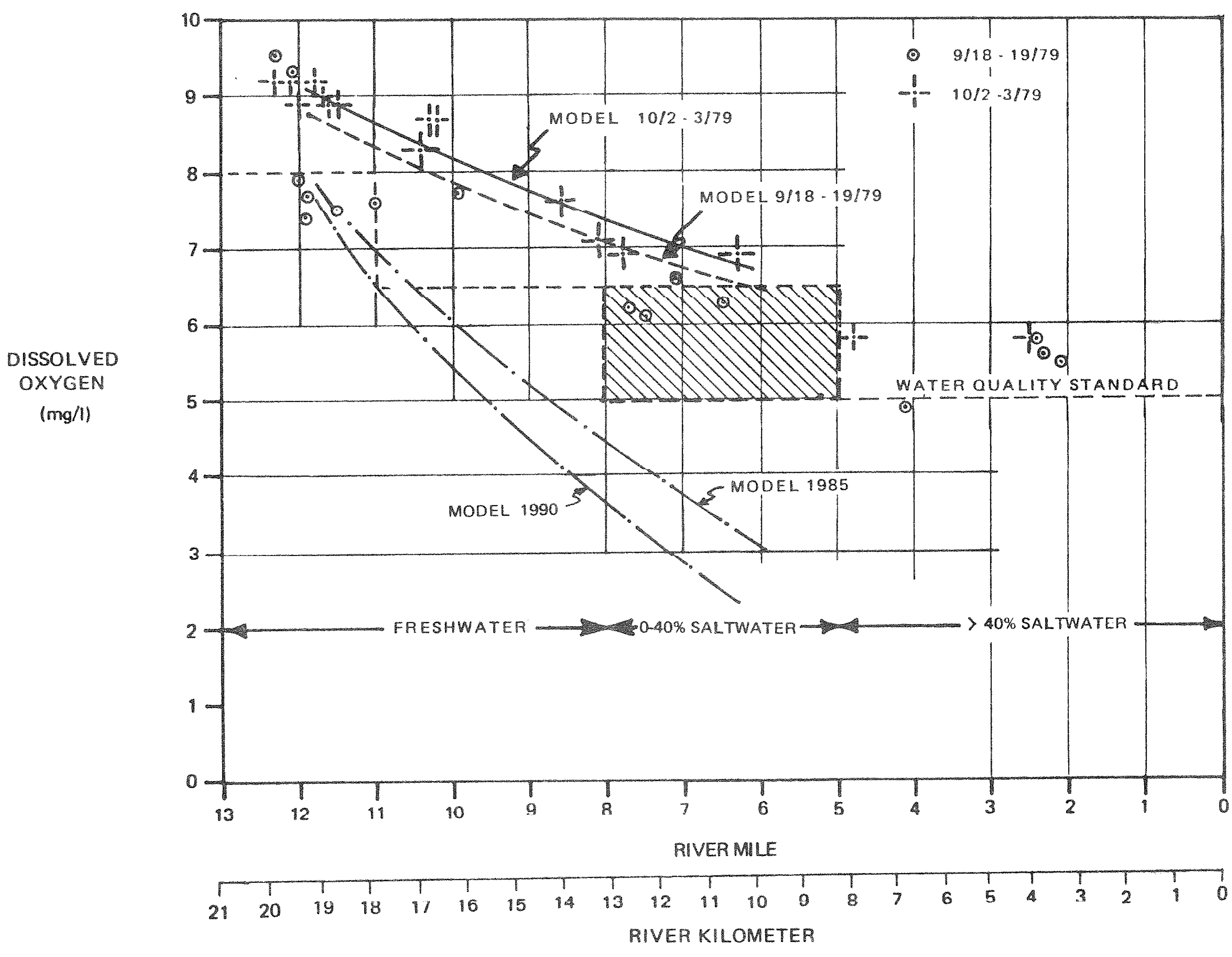
## Model Results

A listing of the model is shown in the appendix. The model was run for the conditions recorded on each of the two time-of-travel studies. The appendix also contains the output from these runs. The results are shown graphically in Figure 8.

There are several observations which can be made regarding the model results. The curve fit on the 10/2-3/79 survey is good. The curve fit for the 9/18-19/79 survey appears to underestimate oxygen depletion. There are two apparent reasons for this:

1. The data points from R.M. 12 to 11 fall substantially below the curve because this drift began in the poor dilution block formed at high tide. Effluent dissolved oxygen concentrations were depressed, and high initial effluent concentrations in this block lowered in-stream oxygen concentrations well below the "average dilution" conditions calculated by the model.

FIGURE 8.




DISSOLVED OXYGEN PROFILE GREEN/DUWAMISH RIVER

2. As noted in the discussion of nitrification rate constant determination, there appears to have been a source of oxygen demand during this drift which was not accounted for in survey or modelling design.

In reviewing the model outputs for these two runs (see appendix), it is important to note that the oxygen depletion due to nitrogenous oxygen demand was greater than 20 times the depletion attributable to carbonaceous BOD. This is particularly important in that several of the dissolved oxygen concentrations found during the surveys were below the applicable water quality standards. In-stream nitrification appears to bear the primary responsibility for depressed dissolved oxygen concentrations in the Green/Duwamish River from R.M. 12 to 6.

To provide an indication of future conditions, the model was run for a set of conditions which could be expected during low river flow conditions in 1985 and 1990. Upriver conditions were those found during the two drift studies. The least favorable conditions from each of the two drifts were chosen:

Upriver flow: 210 cfs

Upriver $NH_4$-N concentration: .08 mg/l

Upriver $BOD_5$ concentration: 1 mg/l

Upriver temperature: 18.45 °C

Upriver dissolved oxygen concentration: 9.2 mg/l

Rate constants were the same as those used in the previous model runs.

Effluent flows were set at 60 and 71 MGD, which were assumed to be an average 12-hour (12 noon to 12 midnight) flow in 1985 and 1990, respectively. These flows were based on a present (1979) dry weather daily average flow of 36 MGD, an annual dry weather flow increase of 1.7 MGD/year, and a noon-to-midnight flow 30% greater than the daily average flow. These assumptions are probably conservative.

Effluent characteristics are based on average September values reported by the Renton treatment plant for the 1977-to-1979 period (Nunnallee, personal communication). These values were:

Effluent $NH_4$-N concentration: 15.2 mg/l

Effluent carbonaceous $BOD_5$ concentration: 7.9 mg/l

Effluent dissolved oxygen concentration: 6.1 mg/l

Effluent temperature was set at 22.5°C, the value recorded on the 9/17-18/79 drift study.

The model output (see appendix) is shown in figure 7 and predicts a severe dissolved oxygen depletion under projected 1985 low flow conditions. Two factors require appropriate care in evaluting these results:

1. The upriver and effluent values chosen do not represent worst-case conditions. The effluent values represent averages; thus these values would be "worse" 50% of the time and under some circumstances might be substantially worse for short time periods. In addition, as noted earlier, there appeared to be an unexplained oxygen demand during the 9/18-19/79 study which could make future conditions worse than projected.

2. The model assumes the continued accuracy of the rate constants used. An in-stream measurement of the reaeration rate ($K_2$) would be helpful. However, perhaps the most critical assumption is that the nitrification rate will remain stable if ammonia loads to the river continue to increase. Nitrification rates in natural streams are by no means clearly defined. It appears, however, that they may be limited or strongly controlled by in-stream ammonia concentrations, population density of nitrifiers, and in-stream oxygen concentrations. At the present time there is no reliable way to predict these effects.

## Conclusions

1. Effluent from the Renton wastewater treatment plant is responsible for dissolved oxygen depletion in the lower Green/Duwamish River during low river flow conditions. Data from time-of-travel studies and modelling of the dissolved oxygen depletion place the present depletion at 2 to 3 mg/l.

2. Detailed analysis of in-stream $NO_2$-N and $NO_3$-N generation, long-term laboratory tests of effluent carbonaceous BOD, and stream modelling indicates that effluent nitrogenous oxygen demand accounts for more than 95% of the in-stream oxygen demand.

3. Low dissolved oxygen concentrations in the effluent depress oxygen concentrations upon initial mixing. The formation of poor dilution blocks during high tide aggravates this phenomenon.

4. Dissolved oxygen concentrations downstream from the plant approached, and in some cases violated, existing water quality standards.

5. Projection of current trends suggests further substantial degradation of the lower Green/Duwamish River as plant flow increases and in-stream dilution ratios decrease.

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APPENDIX

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PROGRAM LISTING

```
 10  DEFFN'30 "Q$=";HEX(22);"DOMOD";HEX(223A);"SCRATCH F Q$";HEX(OD
   )
 20  DEFFN'31 "SAVE DC F$(Q$)Q$";HEX(OD)
 30 REM %
RENTON/DUWAMISH D.O. MODEL

 40 REM BASED ON MODEL BY JOHN YEARSLEY, MODIFIED BY BILL YAKE
 50 DIM X(50),O3(50),D1(50),D2(50),D3(50),R1(50)
 60 INPUT "INPUT TITLE",A$
 70 INPUT "ATMOSPHERIC PRESSURE (MM HG)",P1
 80 INPUT "RIVER DEPTH(FT)",D9
 90 INPUT "NET DOWNSTREAM VELOCITY (FT/SEC)",U1
100 INPUT "UPRIVER FLOW(CFS)",QO
110 INPUT "UPRIVER TEMPERATURE (C)",TO
120 INPUT "UPRIVER NH3-N (MG/L)",NO
130 INPUT "UPRIVER BOD5 (MG/L)",CO
140 INPUT "UPRIVER DISSOLVED O2 (MG/L)",OO
150 INPUT "EFFLUENT FLOW(MGD)",Q1
160 INPUT "EFFLUENT TEMPERATURE (C)",T1
170 INPUT "EFFLUENT BOD5 (MG/L)",C1
180 INPUT "EFFLUENT NH3-N (MG/L)",N1
190 INPUT "EFFLUENT DISSOLVED O2 (MG/L)",O1
200 INPUT "CARBONACOUS RATE CONSTANT (DAY-1,20C)",K1
210 INPUT "NITRIFICATION RATE CONSTANT (DAY-1,15C)",K3
220 PRINT A$
230 PRINT "RIVER DEPTH";D9;"FT"
240 PRINT "NET DOWNSTREAM VELOCITY"; U1;"FT/SEC"
250 PRINT "CARBONACOUS RATE CONSTANT,20C";K1;"DAY-1"
260 PRINT "NITROGENOUS RATE CONSTANT,15C";K3;"DAY-1"
270 PRINT "UPRIVER FLOW";QO;"CFS","EFFLUENT FLOW";Q1;"MGD"
280 PRINT "UPRIVER TEMPERATURE";TO;"C","EFFLUENT TEMPERATURE";T1;"
   C"
290 PRINT "UPRIVER NH3-N",NO;"MG/L","EFFLUENT NH3-N";N1;"MG/L"
300 PRINT "UPRIVER BOD5";CO;"MG/L","EFFLUENT BOD5";C1;"MG/L"
310 PRINT "UPRIVER DISSOLVED O2";OO;"MG/L","EFFLUENT DISSOLVED O2"
   ;O1;"MG/L"
320 PRINT "   "
330 PRINT "FT DOWNSTREAM    OXYGEN CONC       DBOD       DNOD       DTOT
     D7-R1"
340 LO=(5.39*QO*CO)+(8.34*Q1*C1)
350 LO=LO/(1-EXP(-(5*86400*K1)))
360 NO=(5.39*QO*NO)+(8.34*Q1*N1)
370 TO=(TO*QO+1.55*Q1*T1)/(QO+1.55*Q1)
380 OO=(OO*QO+1.55*Q1*O1)/(QO+1.55*Q1)
390 P2=4.879*(EXP(.06378*TO))
400 PO=(P1-P2)/(760-P2)
410 O7=(14.6214-.3898*TO+.006969*(TO↑2)-.00005897*(TO↑3))*PO

420 D7=O7-OO
430 K1=(K1/86400)*((1.045)↑(TO-20))
440 K3=K3*(EXP(.098*(TO-15)))
```

```
450 K3=K3/86400
460 NO=4.57*NO
470 MO=10.6*LOG(D9)-6.05
480  K2=-LOG(1-(2*(((1.42)*(MO/60)*(1.14↑(TO-20))/(H*1*(30.48*DO))↑2
    ))↑.5)))/(MO/1440)
490 K2=K2/86400
500 E0=80
510 F1=U1/(2*E0)
520 A1=1+4*K1*E0/U1↑2
530 A2=1+4*K2*E0/U1↑2
540 A3=1+4*K3*E0/U1↑2
550 B1=1- SQR(A1)
560 B2=1-SQR(A2)
570 B3=1-SQR(A3)
580 FOR X=1000  TO 32000  STEP 1000
590 D1=(K1/(K2-K1))*(EXP(F1*B1*X)/A1-EXP(F1*B2*X)/A2)*LO/(5.39*(QO
    +1.55*Q1))
600 D2=(K3/(K2-K3))*(EXP(F1*B3*X)/A3-EXP(F1*B2*X)/A2)*NO/(5.39*(QO
    +1.55*Q1))
610 R1=D7*(EXP(F1*(1-A2↑.5)*X))/A2
620 D3=D0-(D1+D2)+(D7-R1)
630 % ######              ##.##           ##.##      ##.##      ##.##    ##.##

640 PRINTUSING  630 ,X,ROUND(D3,2),ROUND(D1,2),ROUND(D2,2),ROUND(D
    1+D2,2),ROUND(D7-R1,2)
650 I=X/1000
660 X(I)=X
670 D2(I)=D2
680 D3(I)=D1+D2
690 NEXT X
700 FOR I=1  TO 32
710 NEXT I
```

LINE NUMBER CROSS-REFERENCE

630 - < 1> -- 640

VARIABLE CROSS-REFERENCE

```
A1     <  3> --  520  550  590
A2     <  6> --  530  560  590  600  610  610
A3     <  3> --  540  570  600
B1     <  2>     550  590
B2     <  3> --  560  590  600
B3     <  2> --  570  600
C0     <  3> --  130  300  340
C1     <  3> --  170  300  340
D1     <  5> --  590  620  640  640  680
D2     <  6> --  600  620  640  640  670  680
D7     <  4> --  420  610  620  640
D9     <  4> --   80  230  470  480
E0     <  5> --  500  510  520  530  540
F1     <  6> --  510  590  590  600  600  610
I      <  6> --  650  660  670  680  700  710
K1     <  8> --  200  250  350  430  470  520  590  590
K2     <  6> --  480  490  490  530  590  600
K3     <  9> --  210  260  440  440  450  450  540  600  600
L0     <  4> --  340  350  350  590
M0     <  3> --  470  480  480
N0     <  7> --  120  290  360  360  460  460  600
N1     <  3> --  180  290  360
O0     <  6> --  140  310  380  380  420  620
O1     <  3> --  190  310  380
O3     <  2> --  620  640
O7     <  2> --  410  420
```

VARIABLE CROSS-REFERENCE

```
P0      -<   2>--  400  410

P1      -<   2>--   70  400

P2      -<   3>--  390  400  400

Q0      -<  10>--  100  270  340  360  370  370  380  380  590
                   600

Q1      -<  10>--  150  270  340  360  370  370  380  380  590
                   600

R1      -<   3>--  610  620  640

T0      -<  11>--  110  280  370  370  390  410  410  410  430
                   440  480

T1      -<   3>--  160  280  370

U1      -<   6>--   90  240  510  520  530  540

X       -<  10>--  580  590  590  600  600  610  640  650  660
                   690

* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *

D1()    -<   1>--   50

D2()    -<   2>--   50  670

D3()    -<   2>--   50  680

D3()    -<   1>--   50

R1()    -<   1>--   50

X()     -<   2>--   50  600

* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *

A$      -<   2>--   60  220
```

```
07/07/81                DCMODS                    PAGE  4
 MARKED SUBROUTINE CROSS REFERENCE


 DEFFN'  30<    1> --      10

 DEFFN'  31<    1> --      20
```

SUMMARY

TEXT LINES = 71

TEXT STATEMENTS = 71

LINE NUMBERS = 1

VARIABLES = 43

MARKED SUBROUTINES = 2

9/18-19/79
RIVER DEPTH 6 FT
NET-DOWNSTREAM VELOCITY .73 FT/SEC
CARBONACOUS RATE CONSTANT,20C .09 DAY-1
NITROGENOUS RATE CONSTANT,15C .3 DAY-1

UPRIVER FLOW 274 CFS
UPRIVER TEMPERATURE 18.45 C
UPRIVER NH3-N .08 MG/L
UPRIVER BOD5 1 MG/L
UPRIVER DISSOLVED O2 9.4 MG/L

EFFLUENT FLOW 44 MGD
EFFLUENT TEMPERATURE 22.5 C
EFFLUENT NH3-N 13 MG/L
EFFLUENT BOD5 6 MG/L
EFFLUENT DISSOLVED O2 6.4 MG/L

| FT DOWNSTREAM | OXYGEN CONC | DBOD | DNOD | DTOT | D7-R1 |
|---|---|---|---|---|---|
| 1000 | 8.68 | 0.00 | 0.12 | 0.13 | 0.01 |
| 2000 | 8.60 | 0.01 | 0.21 | 0.22 | 0.01 |
| 3000 | 8.51 | 0.01 | 0.29 | 0.30 | 0.01 |
| 4000 | 8.43 | 0.01 | 0.37 | 0.38 | 0.02 |
| 5000 | 8.35 | 0.01 | 0.46 | 0.47 | 0.02 |
| 6000 | 8.27 | 0.02 | 0.54 | 0.55 | 0.02 |
| 7000 | 8.19 | 0.02 | 0.61 | 0.63 | 0.03 |
| 8000 | 8.12 | 0.02 | 0.69 | 0.71 | 0.03 |
| 9000 | 8.04 | 0.02 | 0.77 | 0.79 | 0.03 |
| 10000 | 7.97 | 0.03 | 0.84 | 0.87 | 0.04 |
| 11000 | 7.89 | 0.03 | 0.92 | 0.95 | 0.04 |
| 12000 | 7.82 | 0.03 | 0.99 | 1.02 | 0.04 |
| 13000 | 7.75 | 0.03 | 1.06 | 1.10 | 0.05 |
| 14000 | 7.68 | 0.04 | 1.13 | 1.17 | 0.05 |
| 15000 | 7.61 | 0.04 | 1.20 | 1.24 | 0.05 |
| 16000 | 7.55 | 0.04 | 1.27 | 1.31 | 0.06 |
| 17000 | 7.48 | 0.04 | 1.34 | 1.38 | 0.06 |
| 18000 | 7.41 | 0.05 | 1.40 | 1.45 | 0.06 |
| 19000 | 7.35 | 0.05 | 1.47 | 1.52 | 0.07 |
| 20000 | 7.29 | 0.05 | 1.53 | 1.59 | 0.07 |
| 21000 | 7.22 | 0.05 | 1.60 | 1.65 | 0.07 |
| 22000 | 7.16 | 0.06 | 1.66 | 1.72 | 0.07 |
| 23000 | 7.10 | 0.06 | 1.72 | 1.78 | 0.08 |
| 24000 | 7.04 | 0.06 | 1.78 | 1.84 | 0.08 |
| 25000 | 6.98 | 0.06 | 1.84 | 1.90 | 0.08 |
| 26000 | 6.93 | 0.06 | 1.90 | 1.96 | 0.09 |
| 27000 | 6.87 | 0.07 | 1.96 | 2.02 | 0.09 |
| 28000 | 6.81 | 0.07 | 2.01 | 2.08 | 0.09 |
| 29000 | 6.76 | 0.07 | 2.07 | 2.14 | 0.10 |
| 30000 | 6.71 | 0.07 | 2.12 | 2.19 | 0.10 |
| 31000 | 6.65 | 0.08 | 2.18 | 2.25 | 0.10 |
| 32000 | 6.60 | 0.08 | 2.23 | 2.31 | 0.10 |

10/2-3/79
RIVER DEPTH 5 FT
NET DOWNSTREAM VELOCITY .5 FT/SEC
CARBONACEOUS RATE CONSTANT,20C .09 DAY-1
NITROGENOUS RATE CONSTANT,15C .3 DAY-1

UPRIVER FLOW 210 CFS
UPRIVER TEMPERATURE 18.45 C
UPRIVER NH3-N .035 MG/L
UPRIVER BOD5 1 MG/L
UPRIVER DISSOLVED O2 9.2 MG/L

EFFLUENT FLOW 31 MGD
EFFLUENT TEMPERATURE 21.7 C
EFFLUENT NH3-N 16 MG/L
EFFLUENT BOD5 5 MG/L
EFFLUENT DISSOLVED O2 9.2 MG/L

| FT DOWNSTREAM | OXYGEN CONC | DBOD | DNOD | DTOT | D7-R1 |
|---|---|---|---|---|---|
| 1000 | 8.97 | 0.01 | 0.23 | 0.23 | 0.00 |
| 2000 | 8.83 | 0.01 | 0.36 | 0.37 | 0.00 |
| 3000 | 8.70 | 0.01 | 0.49 | 0.51 | 0.00 |
| 4000 | 8.57 | 0.02 | 0.62 | 0.64 | 0.01 |
| 5000 | 8.44 | 0.02 | 0.75 | 0.77 | 0.01 |
| 6000 | 8.31 | 0.02 | 0.87 | 0.90 | 0.01 |
| 7000 | 8.19 | 0.03 | 1.00 | 1.02 | 0.01 |
| 8000 | 8.07 | 0.03 | 1.11 | 1.14 | 0.01 |
| 9000 | 7.95 | 0.03 | 1.23 | 1.26 | 0.01 |
| 10000 | 7.84 | 0.03 | 1.34 | 1.38 | 0.01 |
| 11000 | 7.72 | 0.04 | 1.45 | 1.49 | 0.01 |
| 12000 | 7.61 | 0.04 | 1.56 | 1.60 | 0.01 |
| 13000 | 7.51 | 0.04 | 1.67 | 1.71 | 0.02 |
| 14000 | 7.40 | 0.05 | 1.77 | 1.82 | 0.02 |
| 15000 | 7.30 | 0.05 | 1.87 | 1.92 | 0.02 |
| 16000 | 7.20 | 0.05 | 1.97 | 2.02 | 0.02 |
| 17000 | 7.10 | 0.05 | 2.07 | 2.12 | 0.02 |
| 18000 | 7.00 | 0.06 | 2.16 | 2.22 | 0.02 |
| 19000 | 6.91 | 0.06 | 2.25 | 2.31 | 0.02 |
| 20000 | 6.82 | 0.06 | 2.34 | 2.40 | 0.02 |
| 21000 | 6.73 | 0.07 | 2.43 | 2.49 | 0.02 |
| 22000 | 6.64 | 0.07 | 2.51 | 2.58 | 0.03 |
| 23000 | 6.56 | 0.07 | 2.60 | 2.67 | 0.03 |
| 24000 | 6.47 | 0.07 | 2.68 | 2.75 | 0.03 |
| 25000 | 6.39 | 0.08 | 2.76 | 2.83 | 0.03 |
| 26000 | 6.32 | 0.08 | 2.84 | 2.91 | 0.03 |
| 27000 | 6.24 | 0.08 | 2.91 | 2.99 | 0.03 |
| 28000 | 6.16 | 0.08 | 2.98 | 3.07 | 0.03 |
| 29000 | 6.09 | 0.09 | 3.06 | 3.14 | 0.03 |
| 30000 | 6.02 | 0.09 | 3.13 | 3.21 | 0.03 |
| 31000 | 5.95 | 0.09 | 3.19 | 3.28 | 0.03 |
| 32000 | 5.88 | 0.09 | 3.26 | 3.35 | 0.03 |

FUTURE-1985
RIVER DEPTH 5 FT
NET DOWNSTREAM VELOCITY .5 FT/SEC
CARBONACEOUS RATE CONSTANT,20C .09 DAY-1
NITROGENOUS RATE CONSTANT,15C .3 DAY-1

| | |
|---|---|
| UPRIVER FLOW 210 CFS | EFFLUENT FLOW 60 MGD |
| UPRIVER TEMPERATURE 18.45 C | EFFLUENT TEMPERATURE 22.5 C |
| UPRIVER NH3-N .08 MG/L | EFFLUENT NH3-N 15.2 MG/L |
| UPRIVER BOD5 1 MG/L | EFFLUENT BOD5 7.9 MG/L |
| UPRIVER DISSOLVED O2 9.2 MG/L | EFFLUENT DISSOLVED O2 6.1 MG/L |

| FT DOWNSTREAM | OXYGEN CONC | DBOD | DNOD | DTOT | O2-RI |
|---|---|---|---|---|---|
| 1000 | 7.88 | 0.01 | 0.38 | 0.39 | 0.02 |
| 2000 | 7.66 | 0.02 | 0.60 | 0.62 | 0.03 |
| 3000 | 7.44 | 0.02 | 0.82 | 0.85 | 0.04 |
| 4000 | 7.23 | 0.03 | 1.04 | 1.07 | 0.05 |
| 5000 | 7.02 | 0.03 | 1.25 | 1.28 | 0.06 |
| 6000 | 6.82 | 0.04 | 1.46 | 1.50 | 0.07 |
| 7000 | 6.62 | 0.05 | 1.66 | 1.70 | 0.08 |
| 8000 | 6.43 | 0.05 | 1.85 | 1.90 | 0.09 |
| 9000 | 6.24 | 0.06 | 2.04 | 2.10 | 0.10 |
| 10000 | 6.06 | 0.06 | 2.23 | 2.29 | 0.11 |
| 11000 | 5.88 | 0.07 | 2.41 | 2.48 | 0.12 |
| 12000 | 5.71 | 0.07 | 2.59 | 2.67 | 0.13 |
| 13000 | 5.54 | 0.08 | 2.77 | 2.85 | 0.14 |
| 14000 | 5.37 | 0.08 | 2.94 | 3.02 | 0.14 |
| 15000 | 5.21 | 0.09 | 3.10 | 3.19 | 0.15 |
| 16000 | 5.05 | 0.10 | 3.26 | 3.36 | 0.16 |
| 17000 | 4.90 | 0.10 | 3.42 | 3.52 | 0.17 |
| 18000 | 4.75 | 0.11 | 3.58 | 3.68 | 0.18 |
| 19000 | 4.60 | 0.11 | 3.73 | 3.84 | 0.19 |
| 20000 | 4.46 | 0.12 | 3.87 | 3.99 | 0.20 |
| 21000 | 4.32 | 0.12 | 4.01 | 4.13 | 0.21 |
| 22000 | 4.18 | 0.12 | 4.15 | 4.28 | 0.21 |
| 23000 | 4.05 | 0.13 | 4.29 | 4.42 | 0.22 |
| 24000 | 3.92 | 0.13 | 4.42 | 4.55 | 0.23 |
| 25000 | 3.80 | 0.14 | 4.55 | 4.69 | 0.24 |
| 26000 | 3.68 | 0.14 | 4.67 | 4.82 | 0.25 |
| 27000 | 3.56 | 0.15 | 4.80 | 4.94 | 0.25 |
| 28000 | 3.44 | 0.15 | 4.92 | 5.07 | 0.26 |
| 29000 | 3.33 | 0.16 | 5.03 | 5.19 | 0.27 |
| 30000 | 3.22 | 0.16 | 5.14 | 5.30 | 0.28 |
| 31000 | 3.12 | 0.16 | 5.25 | 5.42 | 0.28 |
| 32000 | 3.01 | 0.17 | 5.36 | 5.53 | 0.29 |

FUTURE 1990
RIVER DEPTH 5 FT
NET DOWNSTREAM VELOCITY .5 FT/SEC
CARBONACOUS RATE CONSTANT,20C .09 DAY-1
NITROGENOUS RATE CONSTANT,15C .3 DAY-1

| | |
|---|---|
| UPRIVER FLOW 210 CFS | EFFLUENT FLOW 71 MGD |
| UPRIVER TEMPERATURE 18.45 C | EFFLUENT TEMPERATURE 22.5 C |
| UPRIVER NH3-N .08 MG/L | EFFLUENT NH3-N 15.2 MG/L |
| UPRIVER BOD5 1 MG/L | EFFLUENT BOD5 7.9 MG/L |
| UPRIVER DISSOLVED O2 9.2 MG/L | EFFLUENT DISSOLVED O2 6.1 MG/L |

| FT DOWNSTREAM | OXYGEN CONC | DBOD | DNOD | DTOT | D7-R1 |
|---|---|---|---|---|---|
| 1000 | 7.71 | 0.01 | 0.43 | 0.44 | 0.02 |
| 2000 | 7.46 | 0.02 | 0.69 | 0.70 | 0.03 |
| 3000 | 7.22 | 0.02 | 0.94 | 0.96 | 0.04 |
| 4000 | 6.98 | 0.03 | 1.18 | 1.21 | 0.05 |
| 5000 | 6.74 | 0.04 | 1.42 | 1.46 | 0.06 |
| 6000 | 6.52 | 0.04 | 1.65 | 1.69 | 0.08 |
| 7000 | 6.29 | 0.05 | 1.88 | 1.93 | 0.09 |
| 8000 | 6.07 | 0.06 | 2.10 | 2.16 | 0.10 |
| 9000 | 5.86 | 0.06 | 2.32 | 2.38 | 0.11 |
| 10000 | 5.66 | 0.07 | 2.53 | 2.60 | 0.12 |
| 11000 | 5.45 | 0.07 | 2.73 | 2.81 | 0.13 |
| 12000 | 5.26 | 0.08 | 2.94 | 3.02 | 0.14 |
| 13000 | 5.06 | 0.09 | 3.13 | 3.22 | 0.15 |
| 14000 | 4.87 | 0.09 | 3.33 | 3.42 | 0.16 |
| 15000 | 4.69 | 0.10 | 3.51 | 3.61 | 0.17 |
| 16000 | 4.51 | 0.10 | 3.70 | 3.80 | 0.18 |
| 17000 | 4.34 | 0.11 | 3.87 | 3.98 | 0.19 |
| 18000 | 4.17 | 0.11 | 4.05 | 4.16 | 0.20 |
| 19000 | 4.00 | 0.12 | 4.22 | 4.34 | 0.21 |
| 20000 | 3.84 | 0.13 | 4.38 | 4.51 | 0.22 |
| 21000 | 3.69 | 0.13 | 4.54 | 4.67 | 0.23 |
| 22000 | 3.53 | 0.14 | 4.70 | 4.84 | 0.23 |
| 23000 | 3.38 | 0.14 | 4.85 | 4.99 | 0.24 |
| 24000 | 3.24 | 0.15 | 5.00 | 5.15 | 0.25 |
| 25000 | 3.10 | 0.15 | 5.15 | 5.30 | 0.26 |
| 26000 | 2.96 | 0.16 | 5.29 | 5.44 | 0.27 |
| 27000 | 2.83 | 0.16 | 5.42 | 5.58 | 0.28 |
| 28000 | 2.70 | 0.16 | 5.56 | 5.72 | 0.29 |
| 29000 | 2.57 | 0.17 | 5.69 | 5.86 | 0.30 |
| 30000 | 2.45 | 0.17 | 5.81 | 5.99 | 0.30 |
| 31000 | 2.33 | 0.18 | 5.94 | 6.12 | 0.31 |
| 32000 | 2.22 | 0.18 | 6.06 | 6.24 | 0.32 |